CICOR

Cooperative Institute for Climate and Ocean Research

of the Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

Annual Progress Report

July 1, 2004 - June 30, 2005

Dr. Robert A. Weller, Director

submitted to

National Oceanic and Atmostpheric Administration Ocean and Atmospheric Research (OAR)

September 2005

CICOR 2004 – 2005 Progress Summary

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CICOR – ADMINISTRATIVE OVERVIEW

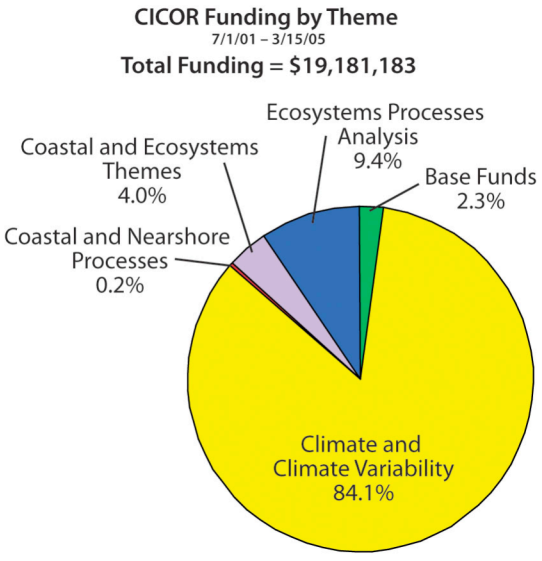
(Cooperative Institute for Climate and Ocean Research)

CICOR is a Cooperative Institute between National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution (WHOI).

CICOR's primary mission is to facilitate and build interaction between NOAA and academia through sponsored research organized around three broad themes. CICOR's closest NOAA Research Laboratory is the Northeast Fisheries Science Center (NEFSC) of the National Marine Fisheries Service (NMFS), which is located near WHOI in Woods Hole, Massachusetts. The Great Lakes Environmental Research Laboratory (GLERL) is CICOR's formal partner within the NOAA OAR structure. CICOR investigators also have research partnerships with other NOAA laboratories, including AOML (Atlantic Oceanographic and Meteorological Laboratory) in Miami, PMEL (Pacific Marine Environmental Laboratory) in Seattle, and the Environmental Technology Laboratory (ETL) in Boulder.

CICOR completed its first cooperative agreement with NOAA OAR, which lasted 3 years, in the summer of 2001. A new 5-year cooperative agreement was signed July 2001. This new agreement was proposed and awarded with indirect cost rates (Laboratory Costs and General & Administrative Costs) that were lower than the overhead rates negotiated with our cognizant agency (ONR). For the duration of the five-year Cooperative Agreement, these rates remain fixed. Since WHOI overhead rates have typically increased each year, the difference between the overhead rates on CICOR proposals and the WHOI rate continues to increase. WHOI however, is required to charge all grants and contracts regardless of funding agency the same overhead rate. This is accomplished by WHOI contributing from its unrestricted funds the difference in overhead on CICOR projects. This contribution was $162,850 in 2004.

In the cooperative agreement CICOR research is organized around three **science themes**. At the same time, for administrative purposes budgets are organized around four **tasks**.

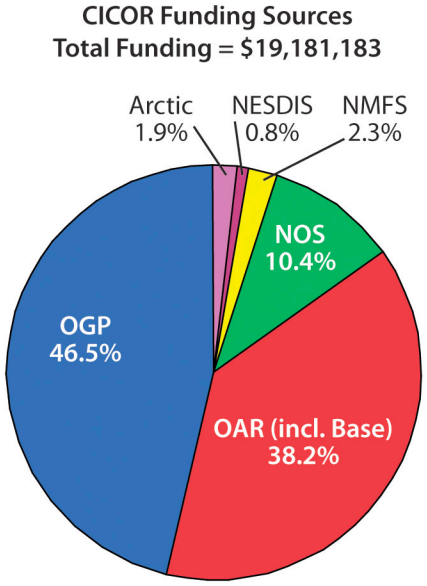


CICOR's three research themes are:

- the coastal ocean and near shore processes,
- the ocean's participation in climate and climate variability and
- marine ecosystem processes analysis.

These theme areas, each of which has significant implications for human society, are interrelated and scientific progress requires collaborations by scientists within and between disciplines. In each case, progress depends on a combination of fundamental process studies, the development and deployment of technological systems for sustained observation, and the development of predictive models that are based on an understanding of the underlying processes and that assimilate information from the observational systems.

CICOR has been in existence for seven years. During the first 3-year Cooperative Agreement it assisted WHOI Scientists with 26 funded projects totaling a budget of $5,817,000. The total amount funded for projects undertaken in the first four years of the present 5-year Cooperative Agreement is $20,472,000. This year, the total amount awarded for projects with start dates of June '05 or earlier is $7,366,541.



The program development fees covered four post-docs and two graduate students, educational outreach, travel support for CICOR PIs and post-docs to attend meetings with NOAA personnel as well as support for short term visitors for seminars and workshops. For more information see the CICOR website: http://www.whoi.edu/science/cicor

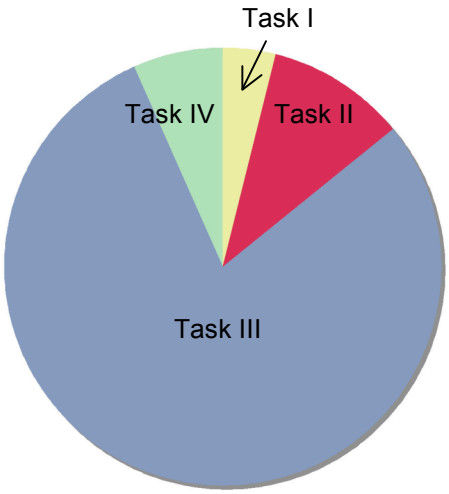
The bulk of the NOAA funds come from the Office of Oceanic and Atmospheric Research and the Office of Global Programs with additional funds from the National Marine Fisheries Service, the National Ocean Service and the NOAA Arctic Program. For purposes of comparison the pie chart to the left shows the funding distribution across the NOAA line offices over the four years of this 5-year agreement and the chart below shows the 2004-2005 year's activity.

2004-2005 CICOR Funding

OAR	OGP	NOS	NESDIS	NMFS	Arctic Program	Off. Of Ocean Exploration
$1,985,000	$4,306,033	$839,620	$146,350	$26,000	$40,998	$20,500
26.95%	58.45%	11.40%	1.99%	.35%	.56	.28%
					Total	**$7,366,541**

Funding to CICOR from NOAA is categorized as falling into four Tasks:

- Task I ($286,441 or 3.89% of the total in 2004-5) supports administration, education, and support for visitors to and from CICOR and outreach activities;
- Task II is research funding with explicit participation by a NOAA investigator ($747,350, 10.15%);
- Task III is research that is in support of NOAA's strategic goals and funds work done by WHOI or other academic investigators without NOAA scientists as co-principal investigators ($5,840,299, 79.28%), and
- Task IV is support for use of WHOI research vessels and submersibles by NOAA and other NOAA-funded investigators ($492,451, 6.68%).



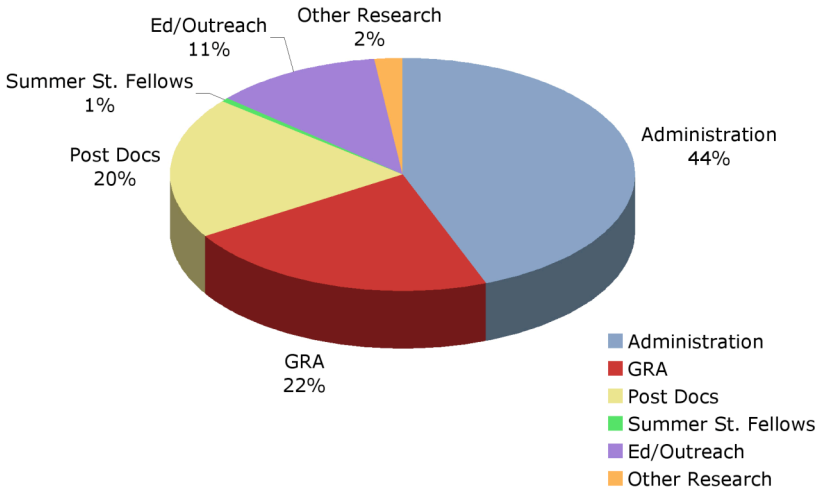
The above includes all funds received for projects with a start date before July 1, 2005. The chart below gives the breakdown of this compares to previous years and includes data as of May 1, 2005.

CICOR Cooperative Agreement July1, 2001 – June, 30 2006					
	Funds Received as of May 1, 2005				
	Year 1	Year 2	Year 3	Year 4	Total
Task I - Administrative, Program Development	222,021	286,256	416,050	237,220	1,161,547
Task II - NOAA Collaborators	385,733	567,467	365,712	668,926	1,987,838
Task III - Support of NOAA mission/goals	2,556,102	3,841,135	4,117,008	4,677,295	15,191,540
Task IV - Facilities	0	0	347,807	492,451	840,258
TOTAL	3,163,856	4,694,858	5,246,577	6,075,892	19,181,183

It is important to bring to the reader's attention that CICOR is an administrative, planning, and facilitation structure serving NOAA, WHOI, and other external investigators funded by NOAA. CICOR investigators respond to NOAA Announcements of Opportunity, submit proposals, and if successful are awarded funds by NOAA through CICOR. The $110K base funds from NOAA OAR and the program development funds are devoted to Task I activities including education, outreach, and increasing engagement in planning and execution of NOAA research. That the principal mode of research is competitive grants funded in response to NOAA announcements is the context for how CICOR manages its science. CICOR has a Board of Fellows, however the Review process lead to the decision to restructure the Fellows for greater effectiveness.

It is believed that the administration costs were particularly high this year due to the labor-intensive preparations and publication costs for the 5-Year Review. CICOR spent a total of $334,440 on administrative, educational and outreach activities, (including the $110,000 NOAA base but excluding the $83,000 of WHOI Administrative support.) The chart below shows the distribution of these costs.

CICOR Administrative funding allocation for 2004-05.



CICOR
Cooperative Institute for Climate and Ocean Research
Annual Report 2004-05

Executive Summary
Robert A. Weller, CICOR Director

CICOR is a Cooperative Institute between the National Oceanic and Atmospheric Administration (NOAA) and the Woods Hole Oceanographic Institution (WHOI). CICOR's specific research themes are the coastal ocean and near-shore processes, the ocean's participation in climate and climate variability, and marine ecosystem processes analysis. CICOR brings to NOAA research excellence in oceanographic research and marine policy and access to research ships and submersibles, remotely operated and autonomous vehicles, and state of the art ocean observing systems.

Education and Outreach activities are key priorities for CICOR. This year CICOR has continued its support of graduate students and Postdoctoral Scholars as well as its participation in a local science fair. It has also initiated further connections with local teachers through making contact with local teachers and helping sponsor a teacher workshop coordinated by WHOI's Academic Program Office and Information Center. We also expect to sponsor part of the coastal exhibit currently being planned by WHOI's Exhibit Center which along with the Information Center hosted over 30,000 visitors in 2004.

NOAA's Teacher At Sea program has continued to be an important component of CICOR outreach. Again this year a CICOR research cruise had two teachers, one a middle school teacher from Batesville, AK and one a middle school teacher from Arica, Chile. The synergy between Mary Cook from Arkansas, Diane Stanitski, NOAA Program Manager for the TAS program, also on board, and the Chief Boatswain of the R/V Ronald Brown, Bruce D. Cowden, illustrator, lead to the making and publication of 40,000 copies of a handsome book, *Teacher At Sea: Miss Cook's Voyage on the Ronald H. Brown.* Ms. Cook and Ms. Stanitski have subsequently visited WHOI and made a presentation to local teachers about the TAS and Adopt-A-Drifter programs. With materials collected during her visit to Woods Hole, Ms. Cook has set up an exhibit about WHOI and Oceanographic research in her school. In September the WHOI Exhibit Center set up an exhibit tracking its own adopted drifter.

CICOR continues to stimulate interaction with the external community by supporting visitors to WHOI and interaction with NOAA laboratories by offering travel support for WHOI investigators who wish to visit those labs to explore possible collaborative research. Examples of visits supported by CICOR was the presentation of Dr. Rafael Bras during his visit with his Research Associate Jinfeng Wang from MIT during which he discussed hydrometeorology and how his group as developed and continues to explore an algorithm to infer surface fluxes like latent heat, sensible heat and ground heat flux from readily available single surface measurements. As a result of this visit Dr. Bras and Ray Schmitt, CICOR investigator from the Physical Oceanography Department at WHOI are working together on a proposal. CICOR has also extended support to investigator Brian Ward for his attendance to a Carbon Dioxide meeting in Boulder, CO. During the 2004-05fiscal year CICOR also planned the summer Indian Ocean Seminar Series which was co-sponsored with WHOI's Ocean and Climate Change Institute. The two-week-long seminar series included lectures and informal discussions with Indian Ocean specialists from China, Australia, the U.S. and WHOI.

The event will result in at least one article in the WHOI publication, OCEANUS outlining the importance and uniqueness of this important region for climate studies.

The JI Directors meeting in the Spring of 04 led to plans to achieve greater involvement of the Joint Institutes in the planning process at NOAA. Part of this plan included the initiative that the Joint Institutes were to host workshops to plan future research activities in areas of key interest to OAR and to populate these workshops with both NOAA and external researchers in order to stimulate interaction between the external community and NOAA OAR during the planning process. CICOR took the lead on developing the first workshop which took place in January of '05, *A Workshop on Planning Coordinated Research on Ecosystems, Climate, and Policy in the Northeast*. The report for the workshop was published in time to be considered for NOAA's internal planning discussions. The workshop focused on developing plans that link research on climate variability, fisheries, and marine policy in the Northeast. More information on the workshop can be found at: http://www.whoi.edu/science/cicor/workshop05/workshop_home.html.

The CICOR 5-Year Review which took place in June 2005 was the office's most significant undertaking of the year. The Review entailed a one-day administrative review and a two-day science review by an external committee organized by NOAA. While the initial comments of the reviewers at the end of the review were largely positive, the formal report is expected to be presented to NOAA's Science Advisory Board in October of 2005. More information on the Review can be found at: http://www.whoi.edu/science/cicor/review/index.html

In 2004, a number of important research activities and results came from NOAA-funded research done in CICOR:

- Don Anderson's ECOHAB project ran a program to make possible rapid community response to bloom events and coordinated U.S. and international workshops and planning efforts addressing improved modeling of HABs. This program was critical in addressing the bloom of red tide that hit the Northeast in the early summer of 2005 which although it resulted in closing down and severely affecting the shell fishing market, resulted in no loss of life.
- Jim Lerczak, Bob Beardsley, and Steve Lentz provided a kinematic and dynamical description of the currents and stratification in the tidal mixing frontal zone on the southern flank of Georges Bank, and the response of the frontal zone to surface wind forcing and intrusions of the shelfbreak front.
- Sandra Castro and Gary Wick's effort, a collaboration with the project Brian Ward is involved in, have provided estimates of the errors in diurnal warming models and have developed their algorithms for linking the skin temperature of the ocean surface, which is what is observed by satellites, with the bulk temperature, which is observed by various in-situ methods.
- Dezhang Chu has studied the use of multibeam sonar for acoustic assessment of fish stocks and developed software to support the use of such hardware for that task.
- Maureen Conte's research uses a novel method based upon the isotopic composition of higher plant-derived leaf wax aerosols to directly quantify large regional scale and temporal patterns of carbon isotopic fractionation of atmospheric CO2 by terrestrial photosynthesis. These data will improve current model estimates of the magnitude and geographical pattern of carbon sinks and lead to a better understanding of how terrestrial sinks are linked to regional climate variability. The study is also generating unique information on the organic composition of aerosols and variations in sources (e.g. biomass burning).

- Dave Hosom and Robert Weller's collection of high quality surface meterological data along long, cross-basin ship tracks using VOS. This data with its high spatial resolution together with the high time resolution Ocean Reference Station data provides the means to investigate spatial as well as temporal variability, to quantify errors and biases in space as well as time, and to support the data assimilative synthesis of improved global flux fields by Lisan Yu.
- Alison Macdonald and colleagues have developed an inverse box model of the Atlantic Ocean that is clarifying how carbon is taken in, stored, and transported by the Atlantic Ocean.
- Breck Owens' group pushed forward the development of the ARGO float technology and constructed and deployed ARGO floats in collaboration with partners at SIO, the University of Washington, and PMEL.
- Bob Pickart, Andrey Proshutinsky, and Carin Ashijan participated in the summer of 2004 in the inaugural cruise of the new Russia- U.S. Census of the Arctic program. The three-leg expedition marks the beginning of this joint, multidisciplinary effort to improve understanding of climate change in the Arctic. Two canyons, the Barrow Canyon and the Herald Canyon, are the paths by which Pacific water enters the Arctic through the Bering Strait. This program carried out the first high-resolution cross-stream survey of Herald Canyon, which is in Russian waters, and greatly improves our understanding of the currents, water masses, and plankton found there.
- John Steele's analysis of an end-to-end food budget for Georges Bank showed that because some predators can switch to different prey that it was essential to management of fisheries resources there to develop a comprehensive food budget including all trophic levels.
- Cynthia Tynan's U.S. GLOBEC project has modeled the occurrence patterns of top predators (cetaceans and seabirds) in the northern California Current System and quantified covariability with changes in forcing from physical and biological processes, providing a basis for the development of a climate-based predictive capability.
- Postdoctoral Investigator Brian Ward contributed to the team effort of developing an improved model of the diurnal warming of sea surface temperature by blending satellite infrared and microwave sea surface temperature data.
- Robert Weller and Al Plueddemann's establishment and maintenance of the unique, high quality Ocean Reference Station time series surface moorings off northern Chile (20°S, 85°W), in the North Atlantic tradewinds (15°N, 51°W) and north of Hawaii and their collaboration with modeling centers and other investigators in the use of this high quality, independent data to illuminate biases and other errors in climatologies, model-based fields, and in remotely-sensed products. The first accurate time series of surface meteorology and air-sea fluxes has been collected under the Peru-Chile stratus deck that plays a key role in Pacific climate variability, and the first quantitative assessment of the upper ocean heat budget in this region has been made.
- The NOAA-NSF funded multi-investigator US GLOBEC Georges Bank Broad-scale group led by Peter Wiebe has produced a comprehensive set of maps of biological (zooplankton biomass and species, nutrients, chlorophyll), and physical variables measured on the 30 cruises taken during the 5 year study period (1995 to 1999). The data sets, krigged to fit a common grid, form the basis for study of monthly and interannual variations of the biological and physical fields on the bank, and the associated climate forcing. Adjoint modeling (conducted by Dennis McGuillicuddy, among others), of one of the target zooplankton species, Calanus finmarchicus, has revealed that this species increase in numbers and biomass on the bank is controlled mostly by local biological processes and not advection from upstream sources.

- Terry Joyce and Jiang Yang have found that atmospheric forcing is essential to the establishment of the tropical Atlantic sea surface temperature dipole, though oceanic transports can act to damp its growth.
- Lisan Yu's production for the Atlantic Ocean of a new, improved air-sea flux product with daily and 1°x1° resolution, verified against high quality mooring and ship data.
- Graduate student Tom Farrar's analyses of air-sea interaction and upper ocean variability at two sites spanning the eastern Pacific cold tongue during the 1997-1998 ENSO event have provided unprecedented quantification of the processes involved in setting sea surface temperatures there.

CICOR Annual Highlights/Accomplishments 2004-2005

Nov. 2004	Teacher At Sea Program Stratus Cruise R/V Ronald H. Brown
Jan. 2005	Co-hosted A Workshop on Planning Coordinated Research on Ecosystems, Climate, and Policy in the Northeast with the Northeast Fisheries Science Center of NMFS, Woods Hole, MA.
Spring 2005	Publication of 40,000 copies of the NOAA book: *Teacher at Sea: Miss Cook's Voyage on the Ronald H. Brown* based on the Stratus cruise of 2004 and dedicated to R. Weller.
March 2005	JI Directors and Administrators Meeting Silver Spring, MD
April 2005	Hosted Rafael Bras from Massachusetts Institute of Technology and his research associate for round-table lunch discussion and afternoon seminar.
June 2005	CICOR Five-Year Review
August 2005	Co-hosted Indian Ocean Seminar Series with the Ocean and Climate Change Institute

Personnel for CICOR Annual Summary Report

July 1, 2004 – June 30, 2005

Task I Support & WHOI Support

Employees	Appt. Dates
Bob Weller, CICOR Director	1999 - present
Patricia White, CICOR Administrator	2004 - present

Task I and Development Costs Supporting Post-Docs and Joint Program Students

Post-Doc	CICOR Theme	Appt. Dates	Advisor(s)
Nicolas Scott	Coastal/Climate	2004-2005	John Trowbridge
Ruoying He	Coastal/Climate	2003-2004	Dennis McGillicuddy Bob Beardsley
Nancy Grumet Prouty	Ecosystem Processes	2004-2006	Konrad Hughen

Graduate Students	CICOR Theme	Appt. Dates	Advisor
Rob Jennings	Marine Ecosystems	2000-2005	Lauren Mullineaux
Tom Farrar	Climate	2004-2005	Robert Weller

Summer Student Fellows	Advisor
Yue (Max) Li	Peter Wiebe (BIO) and Andore Lavery (AOPE)
Chrysanthi Tsimitri	Bob Pickart (PO)
Theresa Black	Dina Erdner and Don Anderson

Tasks II and III Support Summary:

Through CICOR NOAA supported 10 people over 50% time and 92 people less than 50% time.

CICOR Post Doctoral Scholar Summary Reports

Summary of Accomplishment

Dr. Ruoying He – CICOR Post-Doc 2003-2004

Ruoying He arrived at WHOI in September 2003 as CICOR 5th postdoctoral scholar. Since then he has been working on two main research projects. The first project is on the Gulf of Maine coastal circulation and harmful algal transport. This work is a part of the MERHAB (Monitoring and Event Response for Harmful Algal Blooms) project led by Dennis McGillicuddy (WHOI AOPE), Don Anderson and Bruce Keafer (WHOI BO). Ruoying participated in the MERHAB 2003 field survey in the Gulf of Maine where they collected a wonderful set of *in-situ* measurements of physical and biogeochemical variables. He then implemented and tested an adjoint data assimilative ocean model that assimilates coastal sea levels and currents to hindcast the circulation and material transports. Exciting research findings on the utility of data assimilative ocean model and on mechanisms controlling water exchange and transport processes were presented in several scientific meetings and seminars. A paper documenting detailed scientific results is to be submitted for the refereed journal publication. MERHAB 2004 field survey was just completed this summer. With two years *in-situ* measurements, Ruoying is working on another paper focusing on the inter-annual variability of the Gulf of Maine circulation and transport and will submit it for publication shortly. The second research project Ruoying is involved in is the southeast Atlantic coastal ocean observing system. This is a collaborative study with other investigators from University of Miami (UM), Skidaway Institute of Oceanography (SKIO), University of South Carolina (USC), and University of North Carolina (UNC). Ruoying has played an important role in data analyses of surface wind fields and satellite observations, and real time numerical model nowcast and forecast of coastal circulation. Several journal publications have been produced out of this work. Ruoying will start on September 1st as an assistant scientist in WHOI APOE department. Listed below is a short list of Ruoying's research activities so far in 2004.

Journal Publication

He, R., D. J. McGillicuddy, K. W. Smith, D. R. Lynch, C. A. Stock, and J. P. Manning, 2004, Adjoint data assimilation model hindcast of the Gulf of Maine coastal circulation and material transport. *To be submitted*

He, R., Y. Liu and R. H. Weisberg (2004), Coastal ocean wind fields gauged against the performance of an ocean circulation model. *Geophysical Research Letters,* Vol. 31, 14, 14303, doi:10.1029/2003GL019261

Weisberg, R. H., **R. He**, G. Kirkpatrick, F. Muller-Karger, J. J. Walsh (2004), Coastal Ocean Circulation influences on remotely sensed optical properties. *Oceanography*, 17, 68-75

Book Chapter

Weisberg, R. H., **R. He**, Y. Liu, and J. Virmani (2004), West Florida shelf circulation on synoptic, seasonal and inter-annual time scales, *Physical Oceanography in the Gulf of Mexico*, *in review*

Seminar and Presentation

He, R., Shelf and deep ocean interactions, Case studies on the West Florida Shelf. WHOI. December 9, 2003

He, R., Shelf and deep ocean interactions, Case studies on the West Florida Shelf. Marine Science Department, University of Connecticut, February 26, 2004

He, R., Observation and Data Assimilative Model Hindcast of the Coastal Circulation in the Gulf of Maine. Regional Associate for Research on the Gulf of Maine, July 15, 2004

He, R., Understanding and quantifying the deep ocean influence on the coastal ocean, WHOI, July 27, 2004

Research Proposal

Coastal Water Connectivity and Material Transport; PI: **R. He**, submitted to *NSF OCE* 2004 August Panel Review

Summary of Accomplishment

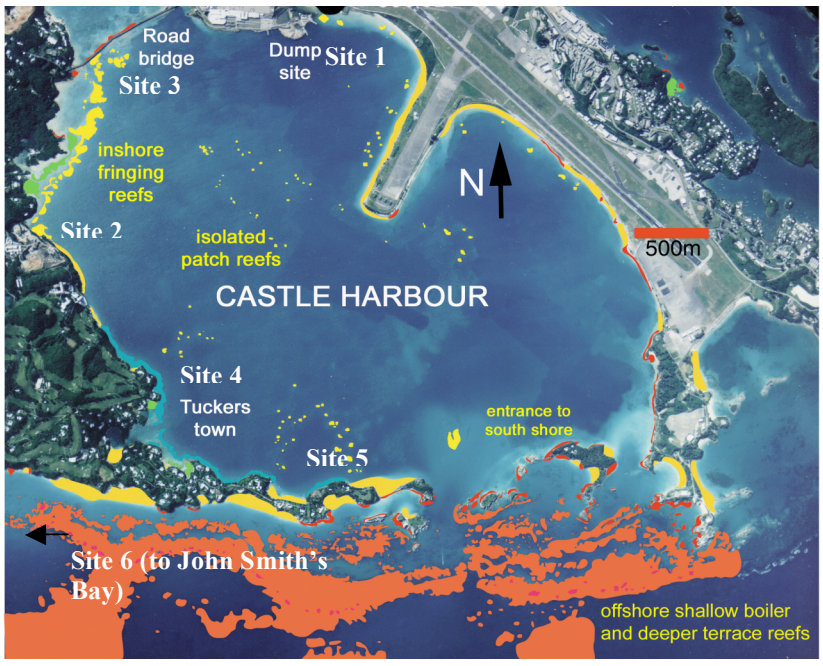
Dr. Nancy Grumet Prouty – CICOR Post-Doc 2004-2005

After arriving at WHOI in mid-September of 2004, I focused on completing my last paper for publication from my dissertation research at Stanford University. This paper is now in press in *Global Biogeochemical Cycles* as the following citation:

N.S. Grumet, M.E. Wickett, P.B. Duffy, K. Caldeira, and R.B. Dunbar (2005). Intrabasin comparison of surface radiocarbon levels in the Indian Ocean between coral records and three-dimension global ocean models, *Global Biogeochem. Cycles*, (in press)

In October of 2004 I participated in a field season to Bermuda to recover sediment cores from Mangrove Lake in order to obtain high-resolution records of past changes and anthropogenic perturbations to the environment such as records of precipitation and the North Atlantic Oscillation. This project is supported by the WHOI Independent and Interdisciplinary Study Awards to Drs. Konrad Hughen and Timothy Eglinton in the Marine Chemistry and Geochemistry Department.

My current research at WHOI involves the development and application of trace metal (i.e., Ba, Cd, Co, Cr, Cu, Fe, Ni, Mn, Pb, and Zn) analysis in order to generate continuous temporal and spatial records of pollution from land based sources in coral cores. This work has focused on the collection and analysis of coral cores from the densely populated island nation of Bermuda where the disposal from the resident and tourist population is one of the most significant environmental problems. In the absence of available space for a land fill, domestic wastes are burned in a mass burn moving grate incinerator. The resulting ash is cement stabililized (formed into cubes) and dumped together with bulk waste (cars, computers) into an inner lagoon, 'Castle Harbour'. There is evidence that dissolution and leaching of contaminants from the dump has led to elevated levels of trace metals in the waters and sediments of Castle Harbour. Metals can also be taken up by scleractinian corals and trace metals have been shown to negatively affect coral physiology and reproductive success. My study sites (see insert) include reefs across the Castle Harbour Basin to form a transect with increasing distance from the bulk waste dump as well as a site from John Smith's Bay, which is exposed to open waters and will allow us to compare a pristine environment to samples from Castle Harbour and serve as a control reference site. By putting current trends and patterns into a historical context, I hope to determine whether coral growth rates have been affected by the recent waste



disposal practices. In so doing I hope to develop a methodology with universal applicability for assessment of the anthropogenic effects of industrialization on coral ecosystems.

Initial laboratory efforts focused on this project have been establishing proper cleaning techniques and blank level concentrations for ultra-trace metal ICP-MS solution analysis. I am in the process of analyzing a relatively young (~10 years old) coral sample adjacent to the airport waste facility dump in order to characterize the polluted end member of the sample transect. In addition, efforts have been made to accurately define the age chronology of the coral by making x-radiographs to capture skeletal growth rates, as well as calibrating the Sr/Ca ratios on the ICP-AES to determine the seasonal sea-surface temperature signal.

In collaboration with my WHOI mentor, Dr. Hughen and colleague at the Bermuda Biological Station for Research, Dr. Ross Jones, I submitted (12/10/04) a proposal to the *NOAA Coral Reef Conservation Grant Program*. Unfortunately this proposal was not selected for final submission. A similar proposal was submitted (4/4/05) to the *Ocean and Climate Change Institute* at WHOI with Dr. Hughen and Dr. Simon Thorrold of the Biology Department to generate multi-decadal reconstructions of trace metal concentrations in coral skeletons from Bermuda.

I am also a co-PI on a proposal submitted (4/4/05) to the *Ocean Life Institute* at WHOI to collect and analyze coral samples from massive *Porites* colonies in the Gulf of Chirique as well as initiate a long-term coral research program based out of the Liquid Jungle Lab on the Pacific coast of Panama. Our proposed work is to reconstruct changes in climatic and environmental conditions throughout the past by using multiple independent proxies measured together on the same samples that will allow us to discriminate signatures from changes in environmental variables such as sea-surface temperature (Sr/Ca), sea-surface salinity (Sr/Ca + $d^{18}O$), runoff and turbidity (Ba/Ca, %Ti, %Al), and nutrient loading (organic $d^{15}N$) that might not be resolvable with a single proxy (e.g., $d^{18}O$). Resulting data sets will allow us to deconvolve the temperature-salinity signal with increased confidence and to quantify the magnitude of sea-surface temperature and salinity anomalies in the eastern Pacific Ocean driven by ENSO events, as well as seasonal migration of the Intertropical Convergence Zone over the past several decades to centuries.

In addition to writing these proposals, I also presented my research as an invited speaker to the Marine Chemistry and Geochemistry Department Seminar and participated in gender equity workshops sponsored by WHOI's Gender Equity Program as well as attended several WHOI Postdoctoral Association meetings.

CICOR Joint Program Student Summary Report

Graduate Student Research Assistants
CICOR provides the framework at WHOI for coordinating NOAA-funded research, for building ties between WHOI investigators and colleagues at NOAA laboratories, and for developing cooperative NOAA-funded research at academic institutions in the northeastern United States. Graduate Student Researchers will be associated with the research activities related to CICOR themes and funded through CICOR. Program development costs support the WHOI-NOAA Cooperative Institute for Climate and Ocean Research educational program.

CICOR is currently supporting two Joint Program Students for the 2004-2005 school year:

Rob Jennings is continuing his graduate studies in the Biology Department and J. Thomas Ferrar, is in his 4th year in the Physical Oceanography Department.

Rob Jennings, Graduate Student

Summary of Accomplishments (Written in Summer 2004)

I have spent most of the past year investigating population genetic variation of the marine polychaete worm Clymenella torquata (a bamboo worm of the family Maldanidae). During the summer of 2002, I collected ~30 worms from each of several sites around Cape Cod (Buzzards Bay, Hyannisport, Stage Harbor, Pleasant Bay, and Barnstable Harbor), as well as from Pembroke, ME and Belmar, NJ. I sampled these sites again in the summer of 2003, and added samples from Chance Harbor, New Brunswick (Bay of Fundy) and Gloucester Point, VA. These worms comprise the study organisms for the first chapter of my dissertation, which consists of a gene flow analysis to determine 1) if the Cape Cod peninsula is an effective biogeographic or genetic barrier between the Gulf of Maine region and the middle Atlantic coast of the U.S., as has often been hypothesized, 2) whether the Cape Cod Canal allows transfer around this putative barrier, and 3) what the patterns of gene flow are in Cape populations of C. torquata. I have sequenced the mitochondrial gene ATP6 (involved in the synthesis of ATP) for approximately 3/4 of the worms collected I am investigating amplified fragment length polymorphism (AFLP) analyses for use as nuclear markers. The data obtained thus far indicate little to no contemporary gene flow (that is, each population bears a distinct genetic signature; see Figure One). There are two main genetic signatures (haplotypes) found in all locations, and rarer closely-related haplotypes specific to each location. The presence of only one genetic signature (haplotype) in New Brunswick and only 3 haplotypes in Maine (2 of them rare) indicate that C. torquata's has recently re-colonized these sites, in contrast to the older populations on the Cape and in New Jersey, where there is considerably more haplotype diversity. This pattern of lower genetic diversity in northern sites is typical of glacially influenced dynamics, where ice sheet advances destroy northern populations, which then slowly return and rebuild genetic diversity during interglacial periods.

In addition to the adult collections described above, I collected juvenile (<3cm) worms from Barnstable Harbor for the second objective of my dissertation. These juveniles should provide a better estimate of dispersal (which involves only organism movement between locations, as opposed

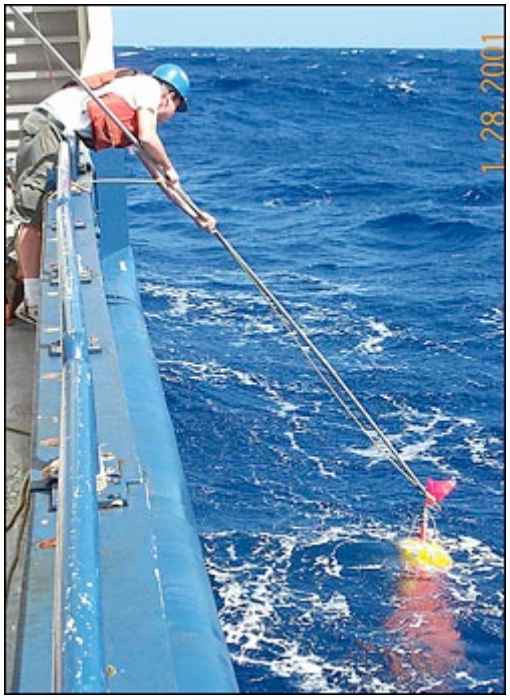
to gene flow which includes survival to adulthood and reproduction in the new location) because most benthic (soft-bottom) invertebrates experience extreme mortality (upwards of 90% in some cases) in the period just after dispersal and settlement. Population genetic studies traditionally sample adults, whose genetic diversity may already have been culled by this post-settlement mortality, thus underestimating the true amount of dispersal that occurred.

My third objective has been to develop a theoretical framework for the issues and complexities introduced by the second objective. No current population genetic models incorporate two-stage (i.e., juvenile and adult) dynamics, nor do they consider the possible effects of severe post-settlement mortality. The third objective thus seeks to interpret any differences seen between the gene flow estimate of the first objective (based on adults) and the dispersal estimate of the second objective (based on juveniles). To further develop the third objective, I traveled to Berkeley, CA, in May 2003 to visit Montgomery Slatkin. Dr. Slatkin is at the forefront of theoretical population genetics, and I discussed with him in general terms the issues and forces that would be important to such a model, as well as its general form. I am hoping this will lead to a more formal collaboration for this chapter of my dissertation.

In the fall semester of 2002, I was the TA for WHOI's new Invertebrate Biology class. The course was designed as a pilot project; it was taught once a week in seminar style, in hopes that it could eventually be built into the sort of full-scale Invertebrate Biology class that WHOI has offered in the past. Professor Stace Beaulieu and I used my trips around the Cape last summer to collect marine invertebrates for the class. TAing this class was a great opportunity for me to help teach the type of class I had just attended in Friday Harbor. I think the course was a great launching point for what will hopefully become a full-time class; the students enjoyed the class thoroughly but cited lack of adequate class time as a serious drawback.

J. Thomas Farrar, Graduate Student

Ph.D. Candidate, MIT/WHOI Joint Program
S.M., MIT/WHOI Joint Program, 2003
B.S. in Physics, U. of Oklahoma, 2000
B.A. in Philosophy, U. of Oklahoma, 2000



Maximum solar heating occurs at latitudes near the equator, warming the sea surface and causing the surface air to rise. As the air ascends high into the atmosphere, it is replenished at the surface by the northeast trade winds from the north and the southeast trade winds from the south. This area of rising air is associated with deep atmospheric convection, heavy precipitation, and weak mean wind speeds. Early sailors were acutely aware of the tendency for weak winds in this region; they labeled this region the doldrums and carefully avoided it. Today, there is renewed scientific interest in the doldrums, also known as the Inter-Tropical Convergence Zone (ITCZ), because the strength and location of this band of convection exerts a profound influence on global weather patterns. The strength and location of atmospheric convection in the ITCZ is primarily determined by the sea surface temperature (SST) field.

Tom began his Ph.D. thesis research in October, 2004 under the supervision of Dr. Robert Weller. This research utilizes a unique data set of upper ocean and surface meteorology measurements from the eastern tropical Pacific to study the processes important in setting SST in the region. The data are from two WHOI surface moorings on 125ºW, one at 3° S in the equatorial cold tongue (a band of cold water that appears annually on the equator in the eastern Pacific) and one at 10° N near the northernmost climatological position of the ITCZ. This research is an outgrowth of Tom's Master's thesis research, which examined the evolution of the upper ocean thermal structure at the northern site.

This research has yielded insight into a mechanism by which the ocean influences the evolution of SST on intraseasonal timescales at the 10ºN site (Farrar and Weller, submitted manuscript). Prominent meridional current fluctuations with a period of about 2 months were observed in the mooring data, and these current fluctuations exerted a strong influence on the local SST, causing it to fluctuate with about a 2 month period from January-June of 1998. The SST fluctuations associated with this signal were substantial, with peak-to-peak amplitudes ranging from 0.5-0.8ºC. Farrar and Weller showed that the SST fluctuations were caused by horizontal advection along the meridional surface temperature gradient.

The two month signal in meridional currents was linked to a previously recognized sea surface height signal that is strongest in the latitude band 9-13ºN east of 120ºW. To resolve discrepancies in prior studies of the signal, Farrar and Weller also worked to characterize the signal observed at the mooring within its larger spatial and temporal context using satellite SST and sea surface height measurements. The signal was found to be associated with relatively short (5-15º wavelength) baroclinic Rossby waves. Farrar and Weller also found evidence that the intraseasonal velocity variability, and its annual cycle, are caused by instability of the westward flowing North Equatorial Current as it intensifies in the spring of each year. It is hoped that this improved understanding of mesoscale oceanic variability and its impact on SST in the region will allow for improved prediction of the oceanic mesocale SST field at monthly to seasonal timescales. This could be particularly important in the region of 9-13ºN in the eastern tropical Pacific, one of the world's most prolific regions of tropical cyclogenesis.

Continuing progress will allow for the completion of the analysis of the data collected at 125°W during 1997-1998 in conjunction with preparation of Tom's Ph. D. Thesis. The effort has shifted to examination of the surface forcing, upper ocean dynamics, and evolution of the thermal structure at 3°S. With that complete, Tom will use remote sensing and TAO data in conjunction with the upper ocean observations and air-sea fluxes from the two mooring sites to extend the effort to identify the important physical processes that drive the evolution of SST and upper ocean thermal structure over the broader region spanning the equatorial cold tongue and in the eastern Pacific warm pool.

CICOR Summer Student Fellowships:

In the Summer of 2005, CICOR supported three Summer Student Fellows, one in each of CICOR's three themes. The Summer Student Fellow Program, coordinated by WHOI's Academic Programs Office, is a highly competitive opportunity for undergraduate students completing their junior or senior year at colleges or universities. Applicants can be studying in any of the fields of science or engineering and have at least a tentative interest in the ocean sciences, oceanographic engineering, mathematics, or marine policy. Fellowships are awarded to pursue an independent research project under the guidance of a member of the Scientific or Senior Technical Staff. These projects typically are suggested by the advisor, and are agreed upon jointly by fellow and advisor. Through this program of Summer Fellowship grants, Woods Hole Oceanographic Institution's (WHOI) aim is to give a promising group of science and engineering students experience, which will assist them in determining whether they wish to devote careers to the study of the oceans. These competitive awards are for a ten- to twelve-week period in the summer, with a stipend of $396 per week and housing provided.

The Summer 2005 Summer Student Fellows were:

1) Yue (Max) Li (Swarthmore College), co-supervised by Peter Wiebe (BIO) and Andore Lavery (AOPE). Peter Wiebe is a WHOI CICOR grant PI.

2) Chryanthi Tsimitri (Aristotle University of Thessaloniki, Greece), supervised by Bob Pickart (PO), who is a WHOI CICOR grant PI.

3) Theresa Black (Western Washington University), co-supervised by Dina Erdner and Don Anderson (BIO). Dina Erdner is in Anderson's lab and Don Anderson is a WHOI CICOR grant PI.

CICOR K-12 Outreach

CICOR has continued its commitment to K-12 educational outreach and has sought ways to expand its reach. CICOR submitted a joint proposal with JIMO to support educational brokers to help scientists become effectively engaged in outreach. CICOR has also strengthened contacts with local science teachers and is pursuing future collaborations New Bedford Oceanarium WOW Mobile (*WithOut Walls*) and its mission "To create an Oceanarium in New Bedford that will educate as it entertains, foster scientific research and awareness of our oceans, and generate jobs and economic development for Southeastern Massachusetts." In addition to the programming initiated by CICOR, many CICOR PIs initiate their own outreach efforts. We include here a sampling of these initiatives.

Rick Rupan who works with Breck Ownes in the Argo Float Program donated vacation time to teach summer program students of the Center for Talented Youth administerd by Johns Hopkins University. Rick spent several days in the summer of '05 working with students at Mount Holyoke College in South Hadley, MA. The students were from the Science and Engineering and Flight Science classes.

A number of CICOR PIs are members of NE-COSEE. The New England COSEE seeks to strengthen the New England region's capacity to develop and provide high-quality ocean science education in both formal and informal settings, by understanding the needs of, working with, and facilitating interactions among educators, researchers, and the public. For example, Al Plueddemann is a member of the NE-COSEE Science Advisory Group and has participated in several workshops geared towards K-12 Outreach.

Another example of NE-COSEE involvement is the active role that Alison MacDonald has taken in Ocean Science Education INstitute (OSEI-II). She has been working with education professionals and, specificaly teachers in Massachusetts New Bedford Global Learning Charter School. Here, she has been bringing physical oceanography concepts and the results of her own research (such as that described in the highlights for NOAA/CICOR grants 37122326 and 31722350) to middle school students, and participating in the larger effort to bring oceanography into Massachusetts' middle school curricula.

U.S. Resesarch Vessel Surface Meteorology Data Assembly Center at Florida State University, Tallahassee, FL annually participates in the FSU Young Scholars Program, by sponsoring the research activities of 2 high school students. The YSP students spend six weeks on the FSU campus taking classes and conducting directed research. They have been involved in the YSP program since 1998.

Teacher At Sea Program Involvement

A strong education and outreach effort within CICOR is its involvement in the NOAA Teacher-at-Sea program (http://www.tas.noaa.gov/). In 2002, the STRATUS research cruise brought a NOAA Teacher-at-Sea for the first time to a non-NOAA vessel, in this case to the *R/V Roger Revelle*, chartered from UNOLS by NOAA for the STRATUS cruise. This Teacher-at-Sea was Debra Brice, from San Marcos, California. A Chilean counterpart, Vivianna Zamarano, a Chilean TAS from Arica, Chile (where the cruise ended) also participated in the cruise and interacted extensively with the science party while providing real time links to classrooms in the United States.

In December 2004, the stratus cruise hosted Mary Cook from Arkansas as the TAS along with Diane Stanitski, a program manager in the NOAA Climate Observation program. During this cruise the NOAA Adopt-a-Drifter program was initiated, in which classrooms "adopt" a surface drifting buoy and subsequently follow its track and data while learning more about the oceans. An amazing interaction developed during the cruise between Mary Cook, Diane Stanitski and the on board science. Together with the Chief Boatswain of the NOAA Ship Ronald H. Brown, they produced a book about this research cruise aimed at middle school students.

When in port in Central and South America, the science party on these cruises to the Stratus Ocean Reference Station regularly participate in interviews with the local press. These dialogs typically cover both the involvement of participants from these countries in the research and questions about ENSO, which has a major impact on these countries. In association with obtaining clearance to sample in national waters, local observers are invited from the countries from which the ship sails and from which the ship docks at the end of the cruise. Additionally, as bunk and lab space is available and as ship time allows, these participants, which include researchers and their graduate students as well as members of the naval oceanographic services of these countries, are invited to participate in the research and carry out their own research projects.

Communication with and support for Stratus Teachers at Sea continues via the CICOR office. All Teachers at Sea associated with the Sratus cruise in the past and scheduled for 2005 have been given memberships to the Oceanography Society and a copy of the back issue, Women in Oceanography. These teachers have also been given subscriptions to the WHOI publication, OCEANUS.

In the last year, WHOI provided use of its high quality video editing facilities to John Kermond of NOAA OGP to develop a short presentation from his extensive video coverage of this cruise. As the STRATUS cruises typically return each year to Arica, subsequent cruises have again provided opportunities for classes from Zamorano's school to learn about oceanographic ships and research.

With the help of CICOR, Mary Cook collected items during her trip to WHOI in August with which

she has made an Oceanography/WHOI exhibit of in a hallway of her school. The exhibit includes chains, wire rope, polypropelene and nylon rope, swages and boots used in the Stratus moorings.

Falmouth High School Science Fair
Held at Falmouth High School, Falmouth, MA
March 4 & 5, 2005

"CICOR Outstanding Project in the Marine Sciences" is awarded every year to a local high school student. A Savings Bond and a certificate are presented with the hope that they will encourage the student to maintain their interest in marine science during their school years. CICOR is proud to have the opportunity to recognize the scientific potential of the youth of the local community

This year's recipient was Amanda Carroll with a project titled, *"The Effects of Diesel Fuel on the Embryo Development of Strongylocentrotus Droebachiensis."*

Abstract

This experiment was designed to see how chemical pollutants such as diesel fuel affect embryo development and thus survival of an important biologic model, the sea urchin Strongylocentrotus droebachiensis. The embryos were exposed to different concentrations of the fuel and the affects on their development were observed for a period of seven hours. After seven hours the stages of the embryos were recorded and condensed into an average. The principle results showed that:

1) a high concentration of diesel fuel such as 0.01% is fatal to the embryos, 2) there was no significant difference between the concentrations of 0.001% and 0.0001% diesel fuel, 3) higher concentrations of diesel yielded more frequent abnormalities in development, and 4) marine paints are more harmful to the embryos when painted on wood rather than plastic.

The conclusions derived from these results were that diesel fuel causes lack of development and mutations in embryos that increase with concentration and that marine paints on wood are more harmful than diesel in some circumstances. Human contamination of ocean environments can lead to the death and mutation of sea urchins.

Children's School of Science
Meteorology Class Fieldtrip to WHOI
August 4, 2005

Jason Smith, Engineering Assistant in the WHOI Upper Ocean Processes Group introduces students to the instrumentation on the Stratus Buoy being prepared for Fall 2005 deployment.

For over fifty years the Children's School of Science has offered summer programming exposing youth to a wide range of science disciplines with an emphasis on hands-on experience. On August 4, 2005 approximately 15 students and 4 adults from the Meterology course visited WHOI for presentations by Jason Smith of the the Upper Ocean Processes Group and Rick Rupan of the Argo Float Lab.

About the Science School

The Children's School of Science encourages and develops in children a love and appreciation of science. Inquiry, direct observation, and understanding of nature is our guiding philosophy. Frequent field trips and hands-on classroom study give students the opportunity to explore nature, become adept at observation, and discover the rules that govern natural processes. The world-famous scientific community of Woods Hole offers additional opportunities to learn about research in different fields. The unusual complexity of the waters, geology and biology of the greater Falmouth area provides a uniquely well suited "live" learning environment.

Courses are organized into six-week sessions and three-week sessions. Classes meet daily Monday through Friday for ninety minutes. Attendance at every class is expected. Courses are organized according to students' interests and age appropriate study. We will begin placing students in classes on April 1st. It is important to have your registration materials in by this date. Please select alternate courses should your first choice be unavailable. We will make every effort to place children in their first choice classes, however, this will not always be possible. Our goal will be to place as many students as possible in a course. Additional courses will be assigned if space is available. First priority is given to children who have taken courses in previous years.
http://www.childrensschoolofscience.org/brochure.htm

Topics in Oceanography Workshop for Educators
Co-sponsored by the WHOI Academic Programs, the WHOI Exibit/Information Center and CICOR
Led by Fiamma Straneo (WHOI Assistant Scientist and former CICOR Post Doc.)

Why Worry About Fresh Water in a Salty Ocean?
Changes in Fresh Water in the North Atlantic and the Impact on Climate Change

August 22, 2005

Agenda

9:30 a.m. Coffee & pastries at **WHOI Exhibit Center**
9:50 a.m. Welcome & orientation
10:00 a.m. Presentation by Fiamma Straneo, WHOI Assistant Scientist, Physical Oceanography Department
11:30 a.m. Special program: Mary Cook and Diane Stanitski, (authors of the book Teacher at Sea, Miss Cook's Voyage on the Ronald H. Brown),
12:00 p.m. Lunch at WHOI dock and informal discussion (Lunch provided)
1:30 p.m. Demonstration of equipment and lab tour
3:30 p.m. End workshop

Moored Profiler Demo (below) and MMP Data explanation (right)

Dr. Straneo with TAS Mary Cook →

Eighteen educators participated in this workshop for which CICOR contributed support for Dr. Straneo's presentation of the McLane Moored Profiler and arranged for the presentations of Mary Cook and Diane Stanitski (authors of the book Teacher at Sea, Miss Cook's Voyage on the Ronald H. Brown). Ms. Cook and Dr. Stanitski provided an overview of the global ocean observing system and ways that teachers can become involved in populating the ocean with scientific instrumentation and conducting real scientific ocean research. Teachers were introduced to NOAA's **Teacher at Sea** (TAS) program and the **Adopt a Drifter Program.**

As a result of the presentation, the WHOI Exhibit Center has adopted a drifter and will track its progress in a permanent exhibit located at the Center which is visited by over 30,000 people annually.

Participants were also given copies of the book *Teacher at Sea, Miss Cook's Voyage on the Ronald H. Brown.*

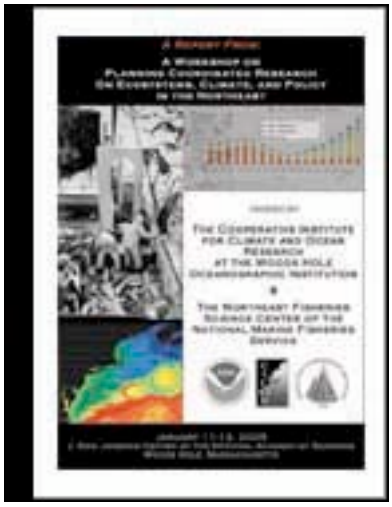
CICOR Seminars and Workshops

Workshop on Planning Coordinated Research on Ecosystems, Climate, and Policy in the Northeast

January 11-13, 2005
J. Eric Jonsson Center of the National Academy of Sciences
Woods Hole, Massachusetts

Hosted by the

CICOR and the **Northeast Fisheries Science Center of the National Marine Fisheries Service, NOAA**



For a copy of the report, visit the CICOR website.

On January 11 to 13, 2005, a diverse group of researchers, program managers, and ecosystem and marine resource managers were brought together to determine the coordinated research needed to support better understanding of marine ecosystems in the Northeast region of the United States and of the impacts of climate variability and the human population on these ecosystems. The long-term goal of such a coordinated research effort is to improve ecosystem-based approaches to marine resources management in the Northeast. Climate variability that changes water properties and transports is apparent at time scales of several years and longer. Marine animals at higher trophic levels live several years or longer. Variability in the catch of finfishes and shellfishes has been seen at the several year and longer time scales. The challenge is to distinguish marine resource changes due to human impacts from those resulting from natural forcing, especially climate variability and change. To initiate discussion, four focus areas were identified prior to the workshop: harmful algal blooms, nutrients and contaminants, fisheries, and biodiversity conservation. Dialog among the participants on the key issues and challenges in these four areas, both from scientific and management perspectives, was used to draw out the common and pressing needs for efforts in the areas of research, observations, modeling, education, and outreach. The workshop concluded by prioritizing the needs and laying out a recommended time line for coordinated research over the next decade.

For more information on the workshop and its findings please see:
http://www.whoi.edu/science/cicor/workshop05/workshop_home.html

Rafael L. Bras
Department of Civil and Environmental Engineering
Massachusetts Institute of Technology, Cambridge, MA 02139

Dr. Bras along with his Research Associate Jinfeng Wang joined WHOI researchers for luncheon discussion and later presented the following lecture in WHOI's Clark Auditorium. Dr. Bras is a CICOR PI and is discussing collaborating with Dr. Raymond Schmitt, (CICOR/WHOI PI) on future research.

Wonders of Planet Ocean: Complexity and Order in Earth Systems

Abstract

Much of the climate, weather and landscape of the earth is mediated by the ever present water. This talk explores the non-linearities of hydrologic processes which commonly lead to chaotic-like behavior yet beautifully organized systems.

Land-atmosphere interactions are discussed first. The dynamic impact on the atmosphere and climate of land surface conditions like soil moisture and vegetation are illustrated. The ideas of multiple equilibria in vegetation and soil moisture, and of maximum evaporation at all times, are discussed.

Self organization in landscape forms are the next topic. Organization in geometry and in surface texture of the river basin is achieved jointly and is the result of highly nonlinear phenomena.

CICOR 5 – Year Review

On June 15–17, 2005 CICOR underwent an administrative and science 5-year Review. The Review gave CICOR an opportunity to reflect on the work that has been conducted over the last four years as well as our administrative practices. It also provided an opportunity for the many people involved with the Institute hear at WHOI to come together with many program managers from NOAA.

The review team is listed below and more information on the Review can be found at: http://www.whoi.edu/science/cicor/review/index.html

Woods Hole Oceanographic Institution
Woods Hole, MA

The Reviewers:

Frank Kudrna, Chairperson
(SAB Member, panel Chair)
Kudrna & Associates, Ltd., Westmont, Illinois 60559

Michael J. McPhaden, Ph.D.
NOAA/Pacific Marine Environmental Laboratory, Seattle, Washington
Website: http://www.pmel.noaa.gov/tao/

Andrew A. Rosenberg, Ph.D.
Ocean Process and Analysis Laboratory, Institute for the Study of Earth, Oceans and Space, University of New Hampshire, Durham, NH

LuAnne Thompson, Ph.D.
School of Oceanography, University of Washington, Seattle, WA 98195

Oceanography (NSF/ONR). She has taught numerous courses both at the undergraduate and graduate level on physical oceanography and climate dynamics.

Yochanan Kushnir, Ph.D.
(Ex-Officio Member)

The Role of The Indian Ocean On Climate
August 8 – 19, 2005

A Seminar Series Sponsored by

The NOAA/WHOI Cooperative Institute for Climate and Ocean Research

RECENT RESEARCH INDICATES THAT THE INDIAN OCEAN IMPACTS CLIMATE around the globe, including the widespread drought from 1998-2002 in the US, southern Europe, and parts of Asia. This realization of the importance of the Indian Ocean to remote climate variability has coincided with a renewed interest in pushing ahead with multinational observing and research efforts in the Indian Ocean. It is timely to catalyze at WHOI and in the United States a dialog about the research and observing systems that would be most effective for developing a better understanding and predictive capability of the coupled ocean-atmosphere variability in the Indian Ocean.

This seminar series brought to WHOI world-renowned experts on Indian Ocean oceanography, meteorology, paleo-oceanography, the societal impacts of Indian Ocean variability, and the value to society of improved understanding of the role of the Indian Ocean in climate.

Seminar participants were at at WHOI during the dates outlined below. Each guest presented at least one seminar, lead one coffee hour and was available to meet with interested staff.

Prof. Toshio Yamagata, Aug. 5 – 12, JAMSTEC & Professor, University of Tokyo

Prof. Roger Lukas, Aug. 5 – 13, Department of Oceanography, University of Hawaii

Dr. Stuart Godfrey, Aug. 5- 23, CSIRO Marine Research, Hobart, Australia

Dr. Chris Charles, Aug. 13 – 19, Assoc. Professor, Geosciences Res. Division, Scripps

Dr. Markus Jochum, Aug. 15 – 19, National Center for Atmospheric Research

Dr. Lisan Yu, PO Department, WHOI

Annual Research Summaries

2005 NOAA/CICOR Progress Report

U.S. Program in Marine Biotoxins and Harmful Algae

Dr. Donald M. Anderson
Biology Department
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
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Program Manager: Susan Banahan, NOAA COP

I. RESEARCH HIGHLIGHTS AND ACCOMPLISHMENTS

The U.S. National Office for Marine Biotoxins and Harmful Algal Blooms is a critical coordination component of the national program for marine biotoxins and harmful algal blooms (HABs), an expanding program that encompasses initiatives ranging from the Ecology and Oceanography of HABs (ECOHAB), Monitoring and Event Response for HABs (MERHAB), two programs on Oceans and Human Health (OHH) involving HABs, and several other ongoing or planned initiatives. The primary objectives for the National Office are to provide organizational and informational support to the academic HAB community and to provide technical support to the HAB management community. Here we provide a description of our major accomplishments and activities during the past four years, with CICOR support.

- World Wide Web homepage – www.whoi.edu/redtide - we continued to expand contents and update information on this national webpage that we maintain. These changes include reports of HAB outbreaks, recent publications, funding opportunities, etc. The webpage is among the top 5 WHOI websites visited each month, typically with over 6,000 visits per month. This home page also generates numerous requests for additional information, photos, or references, which require personal attention. We maintain a central repository for pictures and videos that can be distributed to the public and the media. Another activity in this regard is the creation and maintenance of an e-mail distribution list for the U.S. HAB community. This list is used for announcing meetings, funding opportunities, and other issues of relevance to the broad group of those involved in U.S. HAB research, monitoring, and management. We also continue to update and maintain a list server for the International Society of the Study of Harmful Algae (ISSHA).

- The National Office presently undertakes the unique role of compiling information on HAB events in the U.S. as the ICES *National Coordinating Center for Exchange of Information on Harmful Algal Blooms*. This involves annual efforts interacting with colleagues around the U.S. to compile reports of all national HAB events each year. These data are entered into standard forms and supplied to the ICES Science and Communications Center in Vigo Spain for inclusion in the Harmful Algal Event Database (HAEDAT). Presentations on these bloom reports are also given at annual working group meetings of the ICES Working Group on Harmful Algal Bloom Dynamics. National and international bloom reports are also provided to all U.S. network participants, as well as to other interested parties. This is the

only compilation of U.S. HAB incidents. Decadal maps for all U.S. HAB events are updated annually for ICES as well as posting on the US National HAB web page.

- Administered a Rapid Response Program for HAB Events in the U.S. in cooperation with CSCOR administrators. This involves advertising availability of funds to the HAB community as well as accepting requests for funds and administering their dispersal. The National Office works with NOAA Program Managers to decide who receives funds and how much will be needed in each case. Additionally, we make arrangements and process travel associated with these rapid response activities as well as other budget issues, including vessel charters, equipment rental, etc.

- Assisted with the formulation of scientific agendas, arranging for financial and administrative support, coordinating travel awards, and providing expert representation for numerous national and international HAB workshops, symposia, and conferences. These included: the 11th International Conference on Harmful Algal Blooms (South Africa, November 2004); North Pacific Marine Science Organization (PICES) annual and working group meetings, the ICES (International Council for the Exploration of the Sea) working group on Harmful Algal Bloom Dynamics; GEOHAB Open Science meeting on HABs and eutrophication (March 2005); Second International Conference on Harmful Algae Management and Mitigation (HAMM).

- Directed and organized the *Second Symposium on Harmful Marine Algae in the U.S.* held December 9-13, 2003 in Woods Hole. This involved planning the scientific program; soliciting and compiling abstracts for oral presentations and posters; organizing discussion sessions; obtaining funding for travel awards for students and Postdocs, reviewing applications and making subsequent awards.

- Coordinated the venue for the 3rd U.S. HAB Symposium, scheduled for October 2-7, 2005, by soliciting volunteers willing to serve as hosts, collecting and disseminating descriptions of the possible venue sites, and conducting a vote of the U.S. HAB community. The Office is assisting with fundraising, compiling abstracts for oral presentations and posters; obtaining funding for travel awards for students and Postdocs, reviewing applications and making subsequent awards.

- Assisted with the planning and funding requests for the Second International Conference on Harmful Algae Management and Mitigation (HAMM) held in Qingdao, China November 12-16, 2001. Gave a presentation on the use of the Internet for dissemination of information on red tides and attended several meetings with participants and local scientists regarding national programs for HABs. A technical demonstration was given on information available through the Harmful Algae webpage. In addition, the Office participated in workshop discussions on information technology.

- Assisted with editing, obtaining reviews, and publication of papers submitted for the Proceedings from the *Second International Conference on Harmful Algae Management and Mitigation* (HAMM) held in Qingdao, China November 12-16, 2001.

- Worked with the Marine Institute in Galway on a cooperative program on Marine Science and Technology (NOAA sponsored).

- Served on Planning Committee for a joint US – European Union workshop held in September, 2002 in Trieste, Italy. The workshop addressed the state of the science, gaps in our knowledge and methodologies related to several specific HAB issues of concern to the U.S. and to the EU, working toward a bilateral program on HABs. Assisted with drafting and editing of final report from this workshop – "*The EU-US Scientific Initiative on Harmful Algal Blooms - A Report from a Workshop Jointly Funded by the European Commission - Environment and Sustainable Development Programme and the U.S. National Science Foundation*".

- Organized and sponsored a joint GLOBEC/ECOHAB Modeling Workshop for modelers, state managers and NOAA program managers and scientists to discuss the status of transitioning Gulf of Maine models to operational use. The 2-day workshop was attended by 32 individuals. The National Office provided text and assisted with editing the Proceedings.

- Participated in Oceans and Human Health Roundtable, sponsored by NIEHS and NSF. This workshop served to provide these agencies with scientific input and guidance on issues related to the oceans and human health (OHH) and to lay the framework for a national OHH research program.

- The National Office has a major role in the ongoing revision of the *US. National Plan for Marine Biotoxins and Harmful Algae*. Over the past two years, significant time has been devoted to writing and editing this important guidance and planning document.

- Prepared white paper and gave testimony on harmful algal blooms for U.S. Commission on Ocean Policy report on Oceans and Human Health.

PRESENTATIONS

D.M. Anderson, "Use of molecular probe technologies detection and enumeration of HAB species", ICES Working Group on HAB Dynamics, Bermuda, March 2002.

D.M. Anderson, "The EU-US Programme on Harmful Algal Blooms: A Joint Initiative by the European Commission – Environment and Sustainable Development Programme and the US National Science Foundation", Aberdeen, Scotland, April 2003.

D.M. Anderson, "The Expanding Problems of Harmful Algal Blooms", *International Seminars on Planetary Emergencies*, Erice, Italy, August 2002.

D. M. Anderson, "Coastal Nutrient Pollution and Harmful Algal Blooms", briefing before the House Science Committee, September 24, 2003.

D. M. Anderson, "GEOHAB Science Plan", briefing to Ocean Sciences Program at NSF and to NOAA NOS Administrators, Washington, DC.

D. M. Anderson, "ECOHAB Modeling and Forecasting", briefing to House Science Committee, Washington, DC.

D.M. Anderson. Testimony before the Committee on Science, Subcommittee on Environment, Technology and Standards, U.S. House of Representatives Hearing on the "Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003".

D.M. Anderson. Testimony before the Subcommittee on Fisheries Conservation, Wildlife and Oceans, U.S. House of Representatives Hearing on H.R. 1856, the Harmful Algal Bloom and Hypoxia Research Amendments Act of 2003, February 26, 2004.

PUBLICATIONS

Anderson, D. M. 2003. The expanding global problem of harmful algal blooms. pp. 372-393, in: Ragaini, R. (ed.), International Seminar on Nuclear War and Planetary Emergencies, 27th Session, Erice, Italy, 18-26 August 2002. World Scientific Publishing Co., Pte. Ltd., Singapore.

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Kleindinst, J.L. and D.M. Anderson. 2004. Internet-based communication tools for dissemination of information on harmful algal blooms (HABs), pp. 97-101, in: *Proceedings of the Second International Conference on Harmful Algae Management and Mitigation*, M. Hall, S., Etheridge, S., Anderson, D., Kleindinst, J., Zhu, M., and Zou, Y. (Eds.), Asia-Pacific Economic Cooperation (Singapore): APEC Publication #204-MR-04.2.

Ramsdell, J.S., D.M. Anderson and P.M. Glibert (Eds.). 2005. HARRNESS. Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015. Ecological Society of America, Washington DC, 82 pp. (in press.)

II. SUMMARY OF INTERACTIONS WITH NOAA

The National Office works extensively with the NOS Center for Sponsored Coastal Ocean Research (CSCOR) program in Silver Spring, Maryland at many levels, including communicating to the US HAB community about funding possibilities; coordinating national conferences workshops and symposia; producing assessments and other reports as required by Congress, and so forth. We also work with this program in administering rapid response funds for HAB events throughout the country.

The National Office has been working with the Center for Coastal Environmental Health and Biomolecular Research (CCEHBR), Charleston Laboratory, on a revision of the National Plan, "*HARRNESS. Harmful Algal Research and Response: A National Environmental Science Strategy 2005-2015*".

III. SUMMARY OF EDUCATION AND OUTREACH ACTIVITIES

The National Office maintains a webpage, "Harmful Algae", http://www.whoi.edu/redtide. This website strives to serve as a comprehensive resource for a broad range of user groups, including scientists, managers, the general public, journalists and students. Although there are many HAB-related websites in the U.S., this is the only one that deals with the entire range of U.S. HAB problems and provides access to information on national HAB research programs. It is used as a central repository for information about HABs in the U.S. and every week, this site is one of the top 5 sites visited of all the WHOI websites. We receive numerous requests for specific information, images, etc. from individuals – particularly students and journalists.

The National Office is directly involved in numerous presentations that are given each year to various types of audiences – journalists, students, scientists, etc.

We also distribute many reports and publications, including Proceedings from the various international HAB conferences, *Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters* (published by APEC and IOC), *The Ecology and Oceanography Of Harmful Algal Blooms: A National Research Agenda, Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States*, and other reports.

Analysis of the 1999 Georges Bank Tidal Mixing Front Moored Array Data

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 20
July 1, 2004 through June 30, 2005

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Program Manager: Dr. Lisa Dilling, NOAA – Office of Global Programs

ABSTRACT

As part of this NOAA/WHOI CICOR funded project, the PIs provided support for the processing and analysis of data from a moored array of instruments and other data deployed across the tidal mixing front (TMF) on the southeastern flank of Georges Bank in 1999 by Dr. Ronald Schlitz (NOAA/NMFS) as part of the U.S. GLOBEC Northwest Atlantic/Georges Bank Phase III field program. The focus of this analysis has been on determining the dynamics which drive the tidal and sub-tidal circulation in the vicinity of the TMF and quantifying the structure of the cross-frontal and along-frontal sub-tidal circulation and temperature field as they varied over the 160 day deployment period from early spring, when the water column was homogeneous, to summer, when the water column was highly-stratified offshore of the bank.

PROJECT SUMMARY

The tidal mixing front (TMF), which separates well-mixed water on the crest of Georges Bank from stratified water offshore, is a prominent feature along the perimeter of the bank from late spring through fall of each year. The exchange of physical and biological properties across the TMF influences the supply of nutrients for primary production on the bank, the retention of larval fish and their prey on the bank, and interactions between fish species, their prey and their predators. The advective heat flux driven by the circulation in the vicinity of the TMF may also regulate the heat budget on George Bank. The size and direction of biological exchange and heat fluxes are sensitive to the details of the circulation and thermal structure at the TMF, which varies on seasonal, spring/neap and weather-band time scales.

In this NOAA/WHOI CICOR funded project, the PIs used current, temperature, salinity and bottom pressure data from an array of moorings deployed on the southeastern flank of Georges Bank as well as wind stress data from an NDBC buoy (Fig. 1) to determine the dynamics which drive the tidal and sub-tidal circulation in the vicinity of the TMF and quantify the structure of the cross-frontal and along-frontal sub-tidal circulation as it varied over the deployment period. The array of seven moorings was deployed for a 160 day period during the spring and summer of 1999, spanning approximately 20 km in the cross-bank direction and centered on the 60 m isobath, the typical location of the TMF on the southern flank.

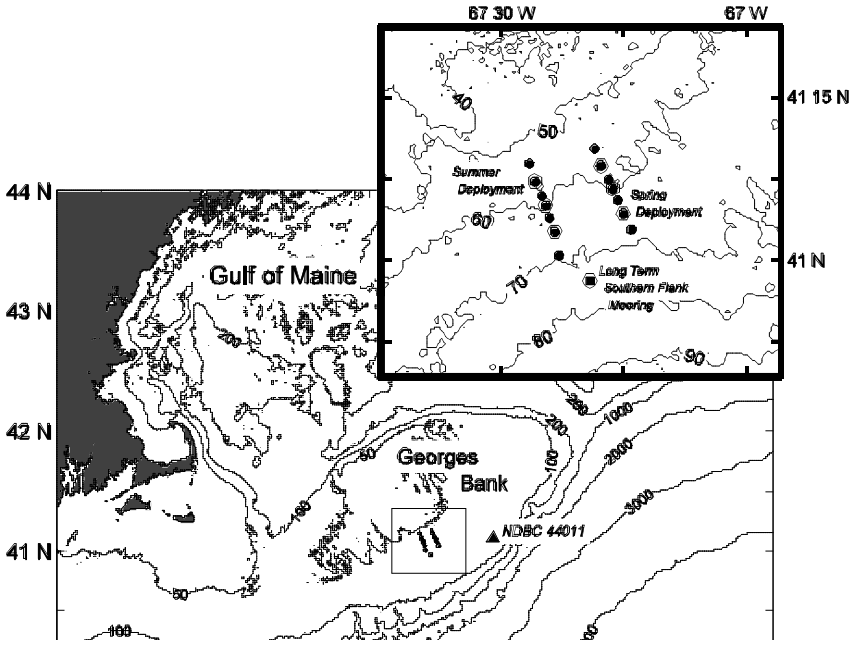

Figure 1. Map of the Gulf of Maine, Georges Bank, and the continental shelf off the northeast coast of the United States, with inset showing the 1999 TMF mooring array configuration on the southeastern flank of Georges Bank. Filled symbols in the inset indicate bottom tripods. Open symbols indicate surface and taut-wire moorings.

The tight spacing between moorings (2 to 3 km), allowed the PIs to determine the dominant balances in the sub-tidal, cross-front momentum equations and the detailed structure of the tidal and sub-tidal cross-front and along-front circulation during early spring, when the water column was well-mixed and the TMF was not present, and during the summer, when a strong thermal TMF was observed. Notably, the cross-frontal tidal stress terms associated with tidal rectification were directly calculated.

The work involved data processing, data quality control, as well as analysis and dynamical interpretation of the data. This work was principally undertaken by Dr. James Lerczak (WHOI).

Most of the processing of the acoustic Doppler current profiler (ADCP), temperature, salinity, and pressure data from the moored arrays was completed by the end of 2003. Inconsistencies in the orientation of the ADCP currents were identified, and corrected current time series were generated. Time series of processed currents, temperature, salinity, and pressure interpolated onto a common time base, and stored as MATLAB files were provided to Dr. Schlitz, and are available for use by other investigators, in particular other scientists involved in the Georges Bank/GLOBEC program.

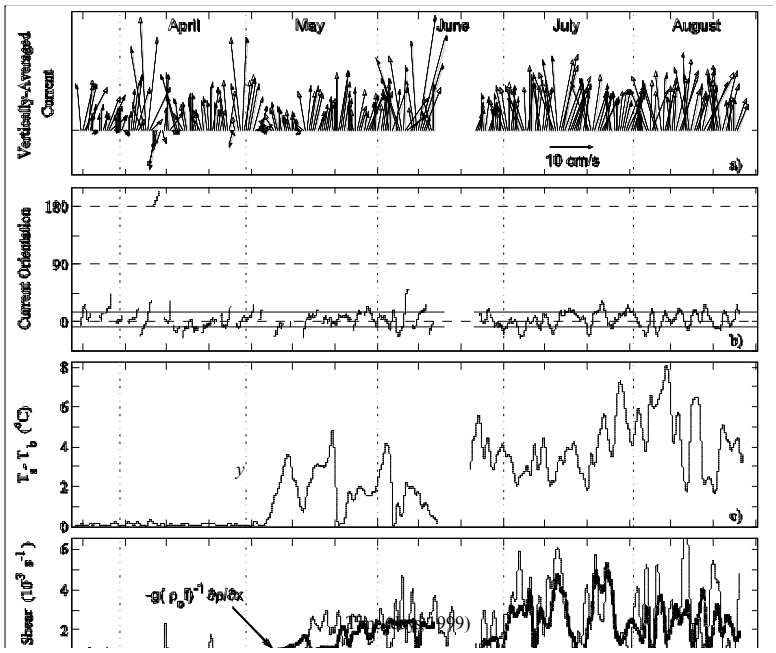

Figure 2. a) Vertically-averaged and cross-sectional averaged sub-tidal currents at the TMF mooring array. Vectors are plotted at 12 h intervals. Upward vectors indicate along-isobath currents in a clockwise sense around Georges Bank. b) Orientation of currents with amplitudes greater than 5 cm/s. An orientation of 0º indicates along-isobath currents directed in a clockwise sense around the bank. Thin horizontal lines indicate ±1 standard deviation about 0º (standard deviation is 12º, excluding the brief reversal at day 97). c) Sub-tidal, surface-to-bottom temperature difference. d) Sub-tidal, vertical shear in along-isobath currents, averaged over water depths between 20 and 50 m below the surface (thin line). Thick line indicates the thermal wind shear, predicted from the sub-tidal, cross-isobath density gradient and averaged over the same portion of the water column as that for the vertical shear.

SCIENTIFIC HIGHLIGHTS

The key scientific results from these analyses are:

• Vertically-averaged, subtidal flow is predominantly in the along-bank direction, clockwise around Georges Bank, with an amplitude as large as 25 cm/s (Figs. 2a and 2b). When stratification is weak (before day 120; Fig. 2c), the current is intermittent and varies significantly in amplitude. During the summer, when stratification is strong (Fig. 2c), the along-isobath flow is less intermittent and has an average amplitude of about 10 cm/s.

• Vertical shear in the subtidal, along-isobath currents increases significantly from spring to summer with the increase in stratification (Figure 2d). This shear is predominantly in thermal-wind balance.

• Cross-bank, tidal Reynolds stress (tidal average of the nonlinear terms vu_y and vv_y) are dominant terms in the sub-tidal momentum budgets. The vertical structure and amplitude

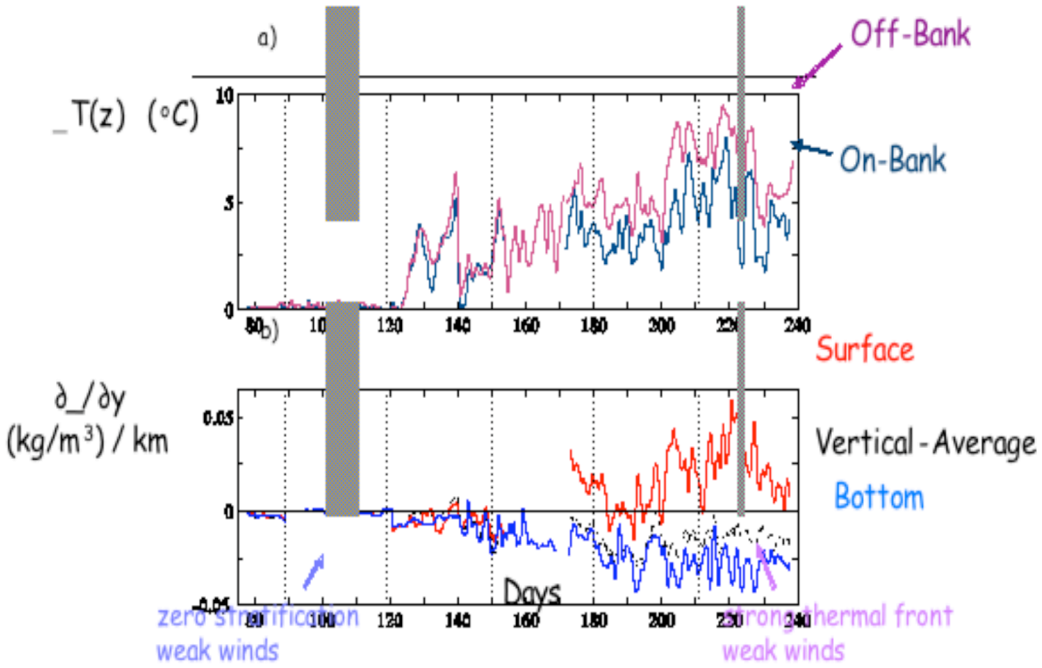

Figure 3. a) Stratification (top-to-bottom) temperature difference at the off-bank-most (red line) and on-bank-most (dark blue line) moorings of the TMF array. During the summer (after day 170) the off-bank mooring tends to be more stratified than the on-bank mooring. b) Cross-bank density gradient near the surface (red line), the bottom (blue line) and vertically-averaged (black line). During the summer months (after day 170), surface water tends to get denser towards the bank, while bottom water tends to get less dense. The vertically-averaged density decreases towards the bank. This cross-bank density structure is the result of more complete vertical mixing at the on-bank mooring than further offshore and is consistent with the presence of a tidal mixing front in the vicinity of the mooring array.

of the tidal Reynolds stress varies with stratification. For example, the vv_y term is vertically uniform when stratification is weak and has a mode two structure when stratification is strong. This term may be important in driving the subtidal, cross-bank flow in the vicinity of the TMF.

• The TMF is apparent in the structure of the density field in the vicinity of the array, but not all the time. During the summer (after day 170), the stratification is stronger off-bank than on-bank (Figure 3a), indicative of the presence of the TMF. This cross-bank variation of stratification is intermittent, at times during the summer being large (pink shaded region in Figure 3) while at other times during the summer being small (e.g., day 202). The presence of the front is also apparent the vertical structure of the cross-bank density gradient (Figure 3b). At the surface water tends to be denser on-bank than off-bank. However, near the bottom, off-bank water tends to be denser than on-bank. The vertically-averaged density tends to be higher off-bank than off bank. This is consistent with the structure of a TMF, for which mixing of the water column is more efficient on-bank of the front and less so off-bank of the front. We believe the short period (~5 to 10 days) variations in stratification and cross-bank density gradient are due to the cross-bank advection of the TMF in the vicinity of the mooring array.

• The different dynamical balances between spring and summer conditions lead to differences in the cross-frontal and along-frontal circulation (Fig. 4). During the spring, the along-bank, sub-

tidal circulation is clockwise (to the southwest), uniform with depth,

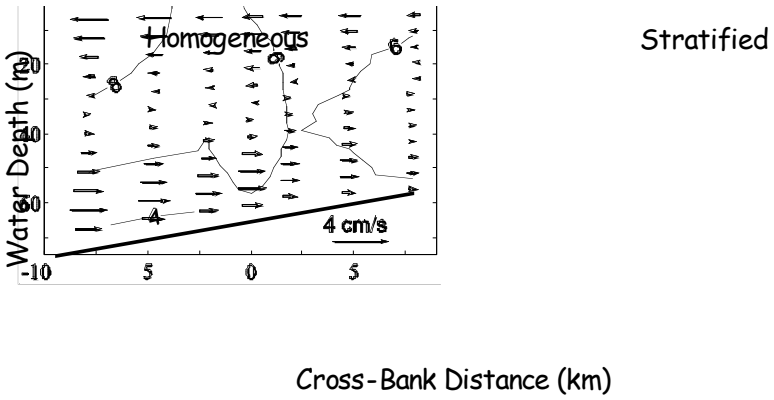

Figure 4. Sub-tidal cross-bank (*v*, arrows) and along-bank (*u*, contours) circulation at the tidal mixing front array. a) Weak winds and weak stratification (light blue shaded area in Fig. 3). b) Weak winds and strong off-bank stratification (pink shaded area in Fig. 3). Contour labels are in cm/s.

with an amplitude of about 8 cm/s. The cross-front circulation is mode-one in structure, with onbank flow near the bottom and offbank flow near the surface, and with an amplitude of about 3 cm/s (Fig. 4a). During the summer, a strong subsurface along-bank jet with an amplitude of 30 cm/s was observed at the TMF. The sub-tidal, cross-front circulation is stronger and more complicated than during the spring. At the location of the jet, the cross-front flow is on-bank in the middle of the water column, with an amplitude of 5 cm/s. The flow is offbank near the surface and bottom of the water column (Fig. 4b).

FUTURE WORK

Two manuscripts are in preparation. The first describes the tidal and sub-tidal barotropic (vertically-averaged) momentum budgets and determines the relative importance of tidal rectification, geostrophy and wind stress in driving the vertically-averaged sub-tidal circulation. This manuscript is anticipated to be completed by the end of spring, 2005. The second describes the vertically-varying sub-tidal circulation and temperature field at the mooring array. The different dynamics driving the cross-frontal circulation during homogeneous conditions and periods when the TMF is present are quantified. This manuscript is anticipated to be completed by the end of the summer, 2005.

The PIs also plan to collaborate with Dr. C. Chen (UMass Dartmouth) and Dr. Schlitz to make detailed comparisons of the structure of the TMF circulation, stratification and fluxes as determined from the mooring array data and those produced by the Finite Volume Coastal Ocean Model (FVCOM).

SUMMARY OF ORAL PRESENTATIONS

Lerczak, J., R. Schlitz, S. Lentz, and R. Beardsley. 2003. Sub-Tidal Circulation at the Tidal Mixing Front: Analysis of the Moored Instrument Array. Presentation at the U.S. Globec Georges Bank Science Meeting. 18-20 November 2003, Rhode Island.

Lerczak, J. A., R. J. Schlitz, R. C. Beardsley. 2003. The seasonally-varying, sub-tidal

structure of the tidal mixing front on the southern flank of Georges Bank. *Eos Trans. AGU, 84*(52), Ocean Sci. Meet. Suppl., Abstract OS51J-09.

Lerczak, J. A., R. C. Beardsley, and R. J. Schlitz. 2004. The dynamics and cross-frontal circulation at a tidal mixing front under well-mixed and stratified conditions. *Eos Trans. AGU, 85*(47), Fall Meet. Suppl., Abstract OS33D-04.

INTERACTIONS WITH NOAA

The tidal mixing front mooring array was collected by Dr. Ronald Schlitz (NOAA/NMFS/NEFSC). Data processing, analysis and interpretation were conducted in collaboration with Dr. Schlitz. In addition, this work was presented at the NOAA sponsored U.S. Globec Georges Bank Science Meeting held in November 2003 at the Whispering Pines Conference Center, Rhode Island.

EDUCATION AND OUTREACH ACTIVITY

This project provided partial support for Dr. James Lerczak in 2002, 2003 and 2004.

Processing and Visualization of Multi-beam Sonar Data

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 42
July 1, 2004 through June 30, 2005

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PROJECT OVERVIEW

Precise, accurate, and efficient estimates of the abundance/biomass of standing fish stocks will provide valuable information for better understanding the marine ecosystem processes. Split-beam echo sounders have been used routinely as primary acoustic survey systems and have provided quantitative information on the abundance and biomass of fish stocks. Multi-beam sonar systems have been used primarily in seafloor bathymetry surveys and not until recently are used in fisheries acoustic surveys. Although the multi-beam sonar systems have a great potential to provide quantitative 3-D images of fish schools and a much more efficient way to estimate the abundance of the fish stocks accurately, there are no standardized quantitative data processing and visualization techniques available. The primary objectives of the proposed work are to streamline the procedures of quantitative multi-beam sonar data processing techniques and to develop a GUI-based software for processing and visualizing multi-beam sonar data.

It is my hope that the results from this project will lead to an improved acoustic assessment of the fish standing stocks and help us to better manage the marine ecosystem.

ACCOMPLISHMENTS

The proposed research consists of three major components: (1) multibeam sonar system calibration experiment; (2) development of the theory and techniques for quantitative multibeam sonar data processing; and (3) development of a GUI-base Matlab software package for implementing the quantitative multibeam sonar data processing.

1. *Multibeam sonar calibration experiment*:

For quantitative acoustic measurements, calibration with high quality is required. From March 5 to March 29, 2004, the calibration experiment was conducted in the sea-well on Iselin Dock at the Woods Hole Oceanographic Institution (WHOI) using the calibration facilities developed under the other projects (NSF OCE-0002664 and NOAA NA97OG0241). The sonar system was the Simrad SM2000/90 kHz provided by the Northwest Fisheries Science Center (NWFSC), NOAA/NMFS (Fig. 1).

The sonar system has 80 receiving channels with an operating option of using the internal or external transmitter. The sonar calibration data include (a) 2-D farfield (23 m) directivity (Fig. 2) and near field (12 m) measurements; (b) beampattern of individual beams (fig. 3); (c) Time-Varied-Gain (TVG) measurement from 0-50 dB with other settings kept the same as or similar to the settings commonly used in the acoustic surveys; (d) influence of pulse duration (150, 300, and 600 ms) on quantitative measurements such as on Target Strength (TS) measurement; (e)

transmit power setting (high/low) on quantitative measurement; and (f) stability and variability measurement by recording the target echoes over a period of time. These data serve as a basis for achieving reliable and quantitative acoustic measurements.

2. *Theory and techniques to quantify the acoustic sonar data*:

To quantitatively estimate abundance and/or biomass of the marine animals such as fish schools from the raw multibeam acoustic data, a theory is developed to estimate the Target Strength (TS) for resolvable echoes and volume backscattering strength (Sv) for overlapping echoes. TS and Sv are the two important quantities in fisheries acoustic applications. The theory takes into account a variety of factors that can potentially affect the estimation accuracy of the interested biological quantities. One of these factors is the inconsistency between the estimated environmental parameters that are set as default parameters in the sonar system and the actual *in situ* parameters for both calibration and field measurements. This is the unique characteristic of the multibeam sonars since the accuracy of the beamformed data depends on the accuracy of the actual sound speed in water. The conversion factor from the raw acoustic data to target strength depends on other system settings including TVG, transmit power, and pulse duration. The equivalent beam angle ψ or its logarithmic equivalence $\Psi = 10\log_{10}\psi$ of each of the individual beams (a total of 128 nominal beams for Simrad SM2000 series), another crucial parameter and has been estimated almost exclusively based on the theoretical prediction due to experimental difficulties, can be determined experimentally (Fig. 4) using the developed theory.

Sensitivity analysis of the system was also performed. These include the dependence of the beamwidth of the mainlobe (θ_w), sidelobe level (SL) on uncertainties in positions of array elements (Fig. 5) and sound speed uncertainty, and beamform weighting function, etc. It is found from Fig. 5 that with 1-mm radial position uncertainty, the sidelobe level increases by about 1.5 dB. In general, the width of the mainlobe is quite stable, but the sidelobe level is much more sensitive to these uncertainties.

3. *GraphicUserInterface(GUI) based Matlab software*:

The software, Quantitative MultiBeam Sonar Processor (QMBSP), is developed specifically for Kongsberg Simrad SM2000 multibeam sonar system but can be easily extended to other multibeam sonar systems such as Reson Seabat 8000 series. The software has a Graphic User Interface (GUI) with multi-layer menu-driven operation options (Fig. 4). The major features of the software include: (a) User defined sonar system configuration with options of default sonar configurations of commonly used Simrad SM2000 multibeam sonar systems; (b) Capability of processing raw and beamformed data; (c) Bottom detection algorithm; (d) Target tracking capability, positions and TS for resolved echoes; (e) Volume Backscattering Strength (Sv) display, which can be easily converted to abundance and/or biomass assessment; (f) Flexible visualization options. The biggest advantage of the QMBSP over the other existing multibeam sonar processing software is its capability of incorporating a full calibration data set.

Figure 1. Calibration facilities on Iselin Dock, WHOI (a) and the multibeam sonar head (b).

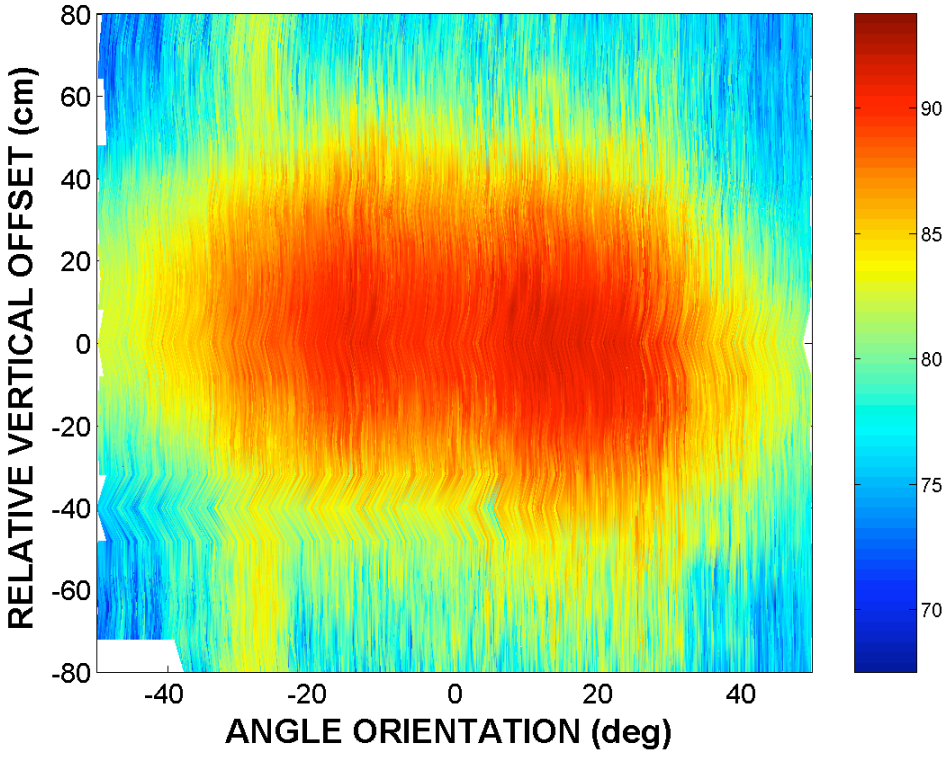

Figure 2. 2-D directivity pattern of SM2000/90 kHz multibeam sonar, measured at 23 m range.

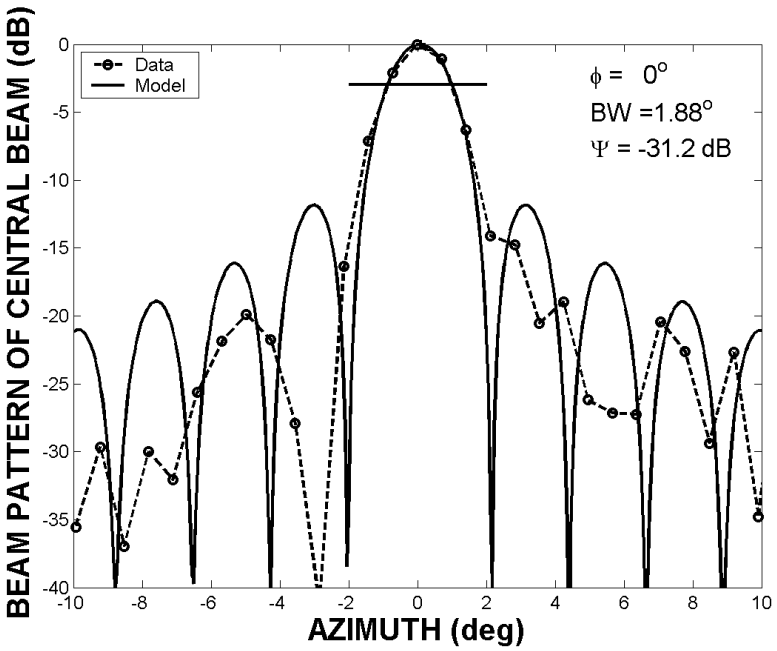

Figure 3. Beampattern of beam at 0°. The 3-dB beam width is 1.88° and the equivalent beam angle in log-scale is –31.2 dB.

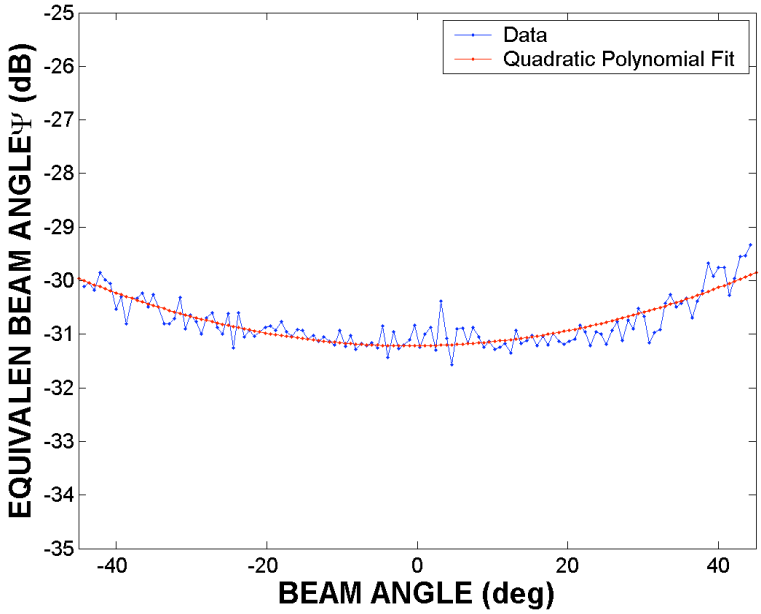

Figure 4. Equivalent beam angles of the SM2000/90 kHz multibeam sonar in log scale.

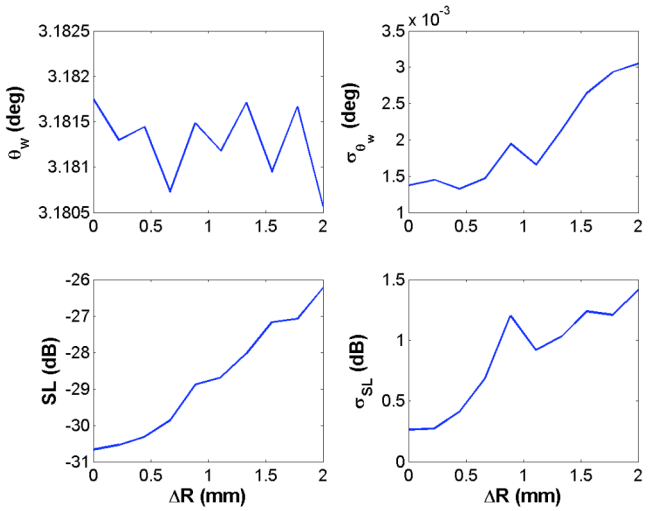

Figure 5. Mean and standard deviation of the mainlobe beamwidth (θ_w) and the sidelobe level (SL) versus position uncertainty (rms) of array elements in radial direction. Simulations based on the parameters of the Simrad SM2000/90 kHz.

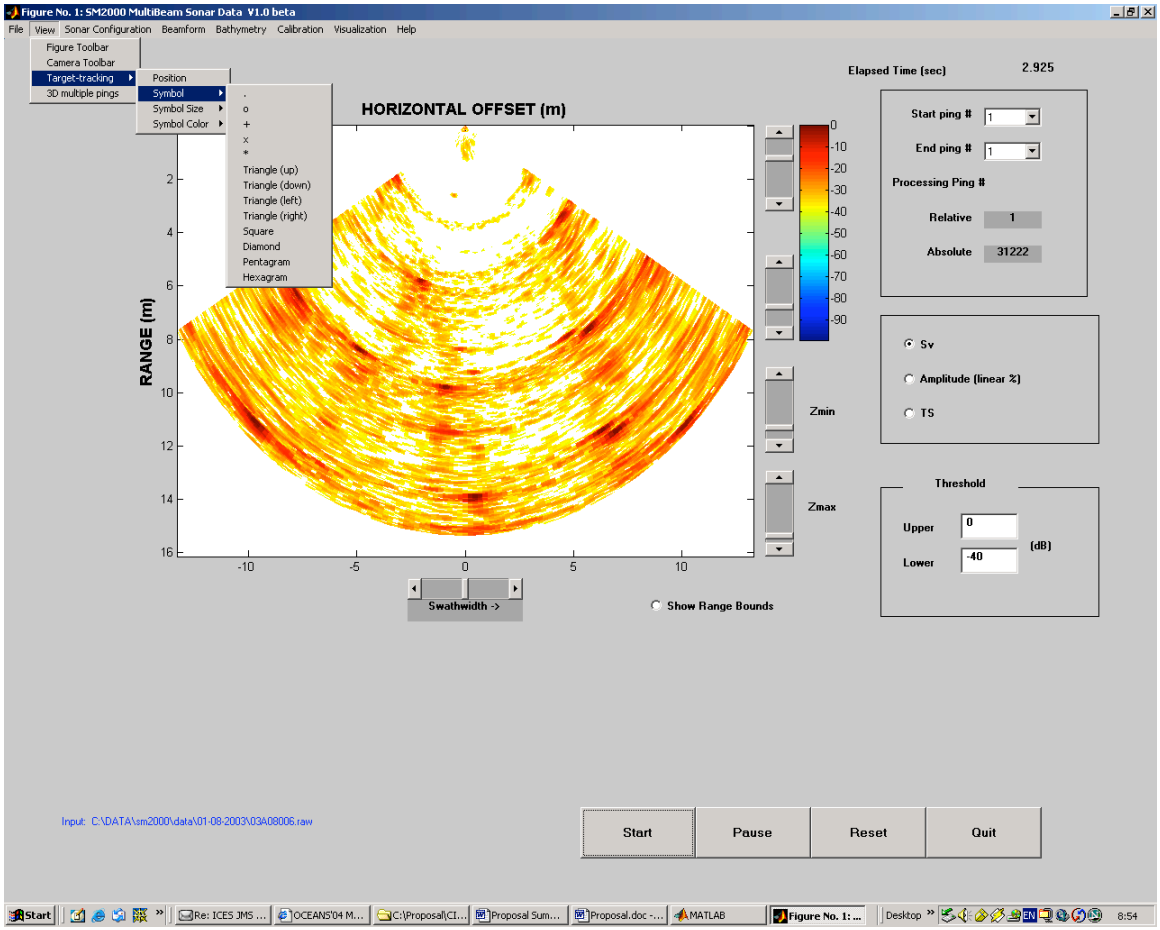

Figure 6. Graphic User Interface (GUI) of the Quantitative Multi-Beam Sonar Processing (QMBSP) software. Dark spots represents echoes from the discrete targets.

PUBLICATIONS

Foote, K.G., D. Chu, T.R. Hammar, K.C. Baldwin, L.A. Mayer, L. C. Hufnagle, Jr., and M.J. Jech. "Protocols for calibrating multibeam sonar by standard-target method", *J. Acoust. Soc. Am.*, in press.

Hufnagle, L.C. Jr.,D. Chu, K.G. Foote, T.R. Hammar, J. M. Jech. Calibrating a 90-kHz multibeam sonar: illustrating protocols. *Proc. MTS/IEEE Oceans' 2004,* Kobe, Japan, pp. 438-442.

Chu D., L.C. Hufnagle, Jr., J.M. Jech, Quantitative acoustic measurements with multibeam sonars (abstract). To be presented at the ICES-Working Group on Fisheries Acoustics Science and Technology, 2005 meeting (WGFAST), April 19-22, Rome, Italy.

SUMMARY OF INTERACTION WITH NOAA

During the first year of the project, a multibeam sonar system, SM2000/90kHz, owned and operated by the Northwest Fisheries Science Center (NWFSC, NOAA/NMFS), was calibrated at the Woods Hole Oceanographic Institution (WHOI) using the calibration facilities developed previously with funding from the National Science Foundation through award number OCE-0002664. Larry Hufnagle, the operator of this multibeam sonar at NWFSC, participated in the entire calibration experiments. Team leader of the monitoring group at NWFSC, Guy Fleischer was also visited the WHOI for two days during the calibration trial. Since the calibration protocols of the multibeam sonar and conventional split-beam sonar systems are quite different, participation in the calibration could certainly provide a good opportunity for the operator to understand and experience the calibration procedures for multibeam sonars. As a result, it will help the acoustic team at the NWFSC to obtain more reliable acoustic assessment of fish stock based on the fully calibrated acoustic data.

I also provided the theoretical formulae to Dr. Mike Jech at the Northeast Fisheries Science Center (NEFSC, NOAA/NMFS), who also serves as the program manager of this project, allowing him to calculating the equivalent beam angle (Ψ) of his split-beam echo sounder based on the measured 2-D beampattern.

I am planning to visit NWFSC in Seattle either next month or in May. The trip will serve multiple purposes: (1) give a talk on application of the acoustic technologies to fisheries applications, emphasizing the multibeam sonar application; (2) show them the new development of the software (QMBSP) that I have been working on; (3) process some of the field data collected during one of their survey cruises last year using the developed QMBSP; (4) refine the software to correct any possible errors in the program; and (5) exchange ideas on scientific research involving fisheries acoustics and explore the potential opportunities for future collaboration.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

Outreach activities: In addition to the presentations in the international workshops and conferences, I have also collaborated with the SonarData Pty. Ltd, an Austrian software company, on improving the quality of their flagship software: Echoview. EchoView is a data

analysis and visualization software package and has been used by many users around world, including different branches of the NOAA/NMFS, as a standard tool for processing split-beam acoustic survey data and fish stock assessment. The recent version of the Echoview (V3.10) is able to process and visualize the multibeam sonar data but only has limited capability of accurately including the calibration data. The discussions and communications between the key personnel from SonarData (Ian Higginbottom, manager and director, and Tim Pauly, director of the Technical Development) and myself last year led to an agreement that I would provide the theoretical formulae needed for more accurate multibeam sonar calibration so they would include the new enhanced calibration capability in the later version of Echoview, and they would allow me to evaluate their software by providing some special features and to ensure the correctness of the new calibration features added to their software. I believe that such collaboration will help the NOAA/NMFS to obtain better acoustic assessment of the fish standing stocks and in turn to better manage the marine ecosystem.

Application of the leaf wax-aerosol method to assess spatial and temporal patterns of carbon isotopic fractionation of atmospheric CO_2 by terrestrial photosynthesis

NOAA Cooperative Agreement No. NA17RJ1223
July 1, 2004 through June 30, 2005

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Program Manager: Kathy Tedesco NOAA/OGP, Climate and Global Change Program

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

Project Background:

Temporal and spatial variations in the concentration and isotopic composition of atmospheric carbon dioxide can be used to estimate the relative magnitudes of the terrestrial and oceanic carbon sinks. Although a powerful approach, sizeable uncertainties in model-derived estimates exist because of our relative lack of understanding of the extent and causes of variability in isotopic fractionation by terrestrial photosynthesis and respiration. An important model parameter is the terrestrial photosynthetic discrimination of CO_2 (D), yet no satisfactory method exists to measure this on large spatial scales. Terrestrial biospheric discrimination of CO_2 (D) reflects the integrated consequences of environmental and physiological factors on photosynthetic processes, and the extent to which D varies on global scales can significantly alter model conclusions. For example, variations in D as a result of water or nutrient stress, or changes in C_3/C_4 productivity associated with ENSO cycles, result in variations in atmospheric $^{13}CO_2$ that could be erroneously interpreted as a shift in the magnitude of the terrestrial sink when in fact none existed.

The major goal of this study is to validate and refine a novel "biomarker"-based method I am developing that uses the carbon isotopic composition of higher plant-derived leaf waxes in aerosols to derive integrated estimates of D and its temporal variation on large spatial scales. The operational plan entails continuous bulk aerosol sampling at four strategically located sites (Bermuda, Barbados, Brazil (Amazonia), Ascension) that receive spatially integrated, well-mixed air masses from key regions representative of major ecosystems. The molecular concentration and carbon isotopic composition of leaf waxes and other key biomarkers (e.g. levoglucosan, a biomass burning marker) will be used to estimate relative contributions of natural and anthropogenic emissions to the nonvolatile organic component and to generate estimates of D for the aerosol footprint. An 18-24 month field program is planned at each site so as to confirm

seasonal trends and also to assess interannual variability in the signal as it relates to climatic variables.

This study should produce the first, direct quasi-hemisphere scale data on spatial and temporal variations in terrestrial photosynthetic discrimination of CO_2. The data generated can be used in conjunction with air mass trajectory analyses to improve current estimates of the magnitude and geographical pattern of carbon sinks. The biomarker data will additionally provide unique information on nonvolatile organic aerosol sources and variations in source intensities associated with changing air transport and temporal trends, and thus complement other atmospheric studies of long range transport of continental emissions and their impact on regional atmospheric chemistry. These products are directly relevant to the NOAA CGCP goal of improving our ability to observe and understand changes in the global environment and the GCC focus on carbon fluxes.

Fiscal Year 2004 Progress:

Sampling campaigns are underway at both the Bermuda and Barbados sites. We have just completed one year of continuous sampling of aerosols at Bermuda (2-week integration period) with no major disruptions. Sampling at the Bermuda tower is scheduled to continue until Apr 2006. Sampling at the Barbados tower began in Apr 2005 and is scheduled to continue for another 1.5 years. Plans are underway for beginning sampling campaigns at Brazil and Ascension Island next year.

Sample analyses are currently underway. Early data indicate molecular differences between the Bermuda and Barbados organic aerosol composition and abundance that are related to differences in air mass trajectories (Fig.) We anticipate presentation of early results at the Fall AGU meeting in December.

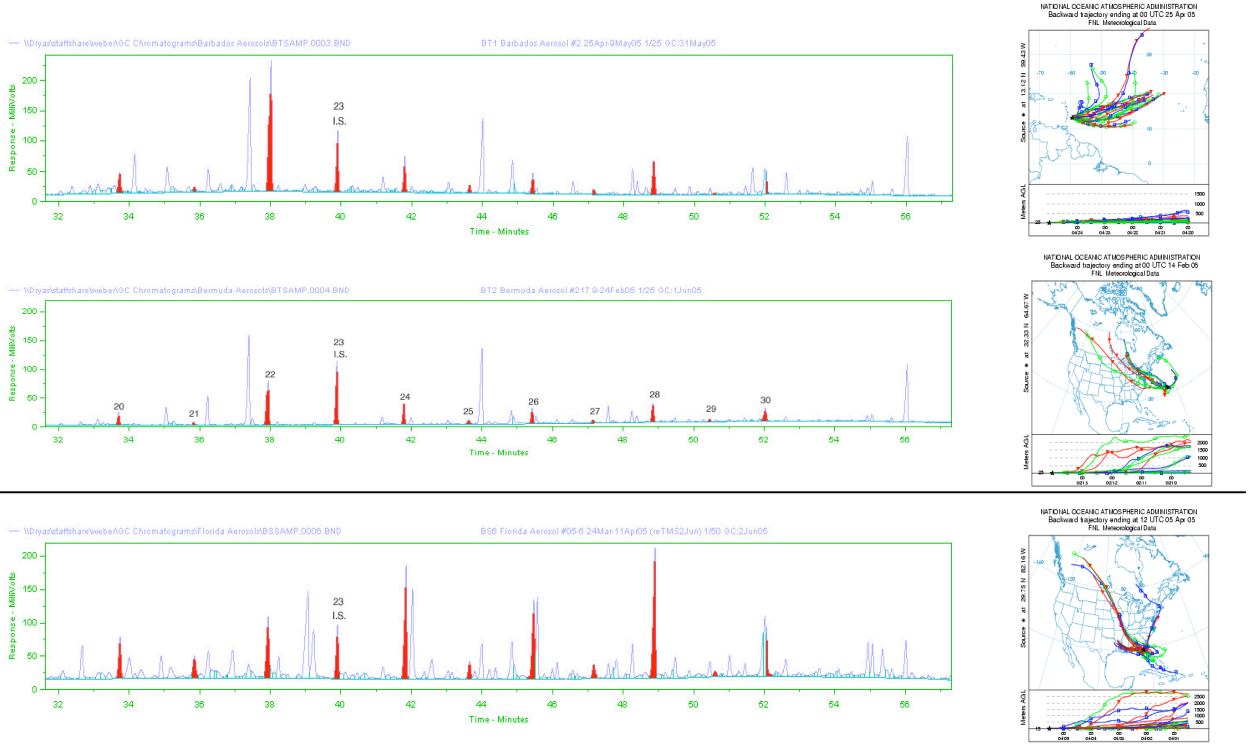

***Figure**. Gas chromatograms of the lipid extractable fraction of organic aerosols collected on Barbados and Bermuda. 5-day back air mass back trajectories (NOAA HYSPLIT model) for the each sampling period are shown at right. For comparison, aerosols collected above the canopy of a slash pine forest in Gainesville, FL is shown in the lower panel. The linear fatty acids of the leaf waxes are highlighted red; the carbon chain length is shown above each peak. The Florida sample has a high abundance of C26-30 n-acids, a distribution characteristic of conifer waxes. The Barbados and Bermuda aerosol distributions have a predominance of lower molecular weight acids and subtle differences in molecular composition between them. Isotopic analyses are underway.*

Multi-Sensor Improved SST (MISST) for GODAE

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 57
July 1, 2004 through June 30, 2005

Dr. Bill Emery[1], Dr. Sandra L. Castro[1] and Dr. Gary Wick[2]
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Program Manager: Dr. Stan Wilson NOAA/NESDIS

Related NOAA Strategic Plan Goal:
Goal 3. Serve society's needs for weather and water information.

1.0 INTRODUCTION

This report documents progress of the NOAA Environmental Technology Laboratory (ETL) and the University of Colorado (CU) towards the second set of milestones established for the first year of the MISST project. The key milestones addressed in this report are to provide initial estimates of errors in diurnal warming models and to define an initial model for relating skin and bulk temperatures. Because these activities were carried out jointly at NOAA ETL and CU, the documentation has been consolidated into a single report.

2.0 INITIAL SKIN BULK MODEL

The ability to relate sea surface temperature (SST) retrievals at different effective measurement depths is required to enable the production of a blended multi-sensor SST product. The methodology must be able to account both for the presence of diurnal warming and the oceanic skin layer. This section introduces an initial method for estimating the temperature change across the skin layer and presents the corresponding expected errors. Effects of diurnal warming will be considered in the following section.

While many models have been developed to describe the temperature change across the oceanic skin layer, application to this project requires a model with inputs that can be obtained easily and accurately from satellite data. More detailed models for the skin layer consider the impacts of both the net heat flux across the interface and the local wind speed, but estimating the heat flux from satellite data remains challenging. The model proposed for the initial version of the GHRSST-PP data processing specification, taken from Donlon et al. (2002), is a function of wind speed only. Similar formulations based on wind speed only were explored by Castro (2001).

The accuracy of these wind speed based estimates was evaluated with new independent measurements of the bulk-skin temperature difference and satellite-derived wind speed

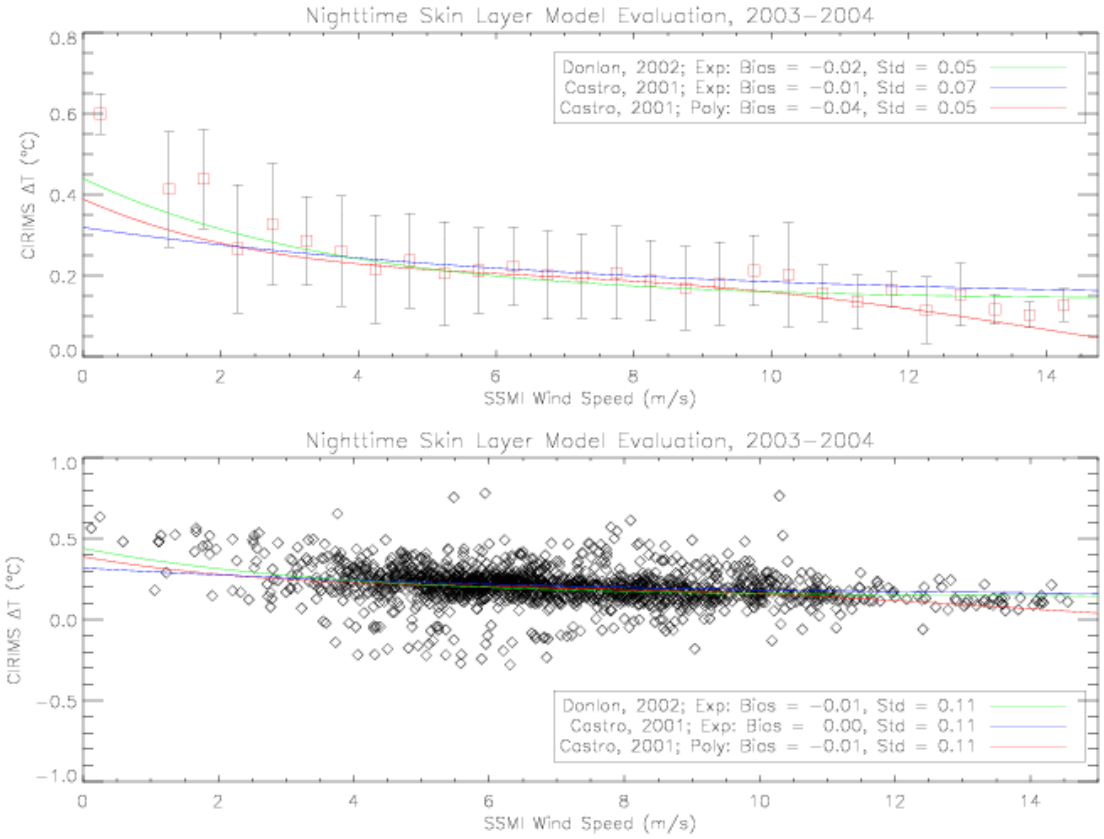

Figure 1. Evaluation of initial skin layer models.

estimates. Use of satellite-derived wind speeds will provide a better estimate of the accuracy that can be achieved in this project where only satellite-derived products are available. Observations of the bulk-skin temperature difference were collected in 2003-2004 aboard the R/V Ronald H. Brown by Dr. Andrew Jessup of the Applied Physics Laboratory using the Calibrated Infrared In Situ Measurement System (CIRIMS) and through the hull temperature sensors at depths of 2 and 3 m. These observations were matched with retrievals of the wind speed from the Special Sensor Microwave Imager. To ensure matches with most surface observations and to evaluate the potential impact of lack of simultaneity with the wind speed retrievals, matches were initially collected at time separations up to 12 hours. The large set of matches was then further constrained through various different techniques including tightening the time matchup window, averaging the observations matched with a satellite retrieval, and considering only the match closest in time to each satellite retrieval.

Representative results for nighttime observations when diurnal warming effects are minimal are shown in Figure 1. The lower panel shows the individual observations while the upper panel shows the results binned by wind speed range. For both cases, the proposed models are overplotted along with their corresponding statistics. The formulation of each of the models is given as follows:

Donlon, 2002: $DT = 0.14 + 0.30 \exp(-0.27\ U)$
Castro exponential, 2001: $DT = 0.138 + 0.181 \exp(-0.135\ U)$
Castro polynomial, 2001: $DT = 0.389 - 0.075\ U + 0.12\ U^2 - 9 \times 10^{-4}\ U^3 + 2.2 \times 10^{-5}\ U^4$

All the models generally reproduce the observed behavior of the independent observations though the data suggests perhaps a slightly greater rate of increase in the bulk-skin temperature

difference at the lowest wind speeds. The overall bias is lowest with the Castro exponential model but the rms differences are slightly reduced with the Donlon model. The curvature of the data is best fit currently with the Donlon model. The accuracy observed relative to the individual observations is only slightly poorer than that obtained with coincident in situ wind speeds and should be sufficient for an initial bulk-skin model.

Based on these results, the Donlon model appears acceptable for use as the initial skin layer model for MISST, consistent with the initial GHRSST data processing specifications. The apparent tendency for a more rapid increase in the bulk-skin temperature difference at low wind speeds will be further investigated with additional data sets and, if appropriate, a revised fit will be derived for the next milestone to better capture the observed behavior.

Further work to be conducted prior to the next deadline will also explore whether the accuracy can be improved through considering additional effects. The results of Castro (2001) showed a strong residual dependence on heat flux. Various satellite-derived flux products will be tested to determine if they can be retrieved accurately enough to enable an improvement in the estimation of the bulk-skin temperature difference.

3.0 ERRORS IN DIURNAL WARMING

Multiple simplified models for diurnal warming have been proposed both within the GHRSST framework and in independent work. Within MISST, parameterizations predicting the diurnal warming expected for infrared and microwave satellite retrievals were developed by C. Gentemann from empirical observations. Independent parameterizations were developed previously by Webster et al (1996) and Kawai and Kawamura (2002) from output of more complex mixed layer models. The focus of this activity was to provide an independent estimate of errors in these parameterizations to help derive error estimates for diurnal corrections and to identify conditions where further refinement of the diurnal warming models might be required.

The models were evaluated using detailed direct observations of diurnal warming and associated meteorological conditions from a set of research cruises conducted by the surface processes group at ETL. The depth of the temperature measurements used for the observations of diurnal warming was slightly less than 50 cm. Wind and insolation data were used as inputs to the parameterizations as appropriate and the results compared with the observations. The MISST parameterizations require only wind and time inputs since insolation is estimated within the parameterization. The primary quantity evaluated was the predicted amplitude of peak diurnal heating. The estimated timing of peak warming was also investigated for those models providing information on timing. The observations were carefully filtered for cases where the temperatures before and after diurnal warming agreed closely to eliminate the influence of effects related to advection and motion of the observing platform.

Results of the evaluation of predicted amplitude are shown in Figure 2 both for all observations and only those at low wind speeds where significant diurnal warming would be expected. Summary statistics are also included in Table 1. Interpretation of the results for the Gentemann parameterizations are complicated by the fact that they were derived specifically for satellite retrievals with different effective depths and that may have residual components of the diurnal cycle incorporated. For the Gentemann parameterizations, the MW formulation predicts more warming than that observed at 50-cm depth when the warming is small, while the IR formulation predicts less warming when the warming is large. Relative to the actual observations, the best results are provided by the Webster et al. model.

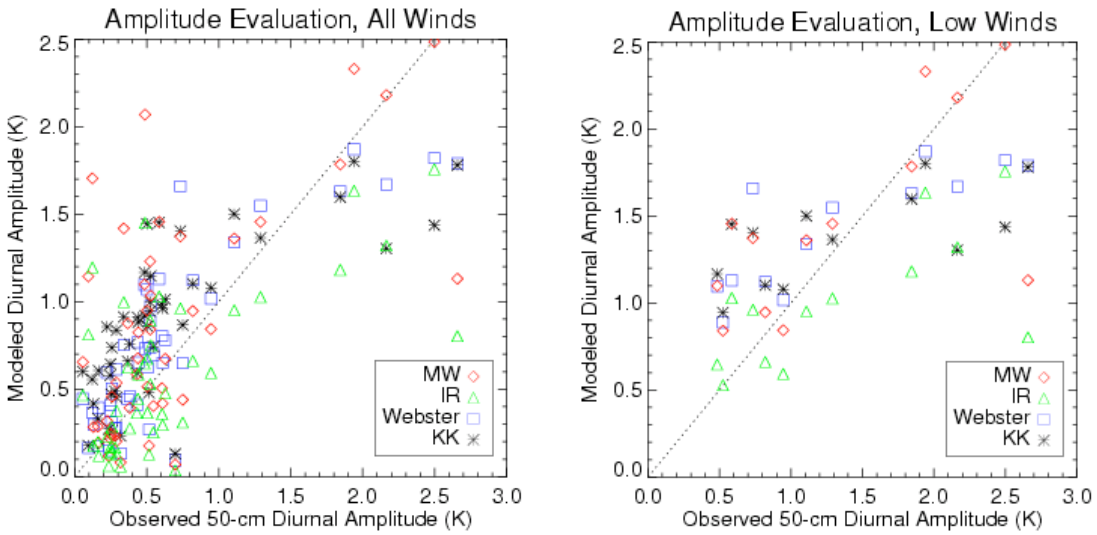

Figure 2. Evaluation of the accuracy of modeled peak daily diurnal SST relative to direct observations at 50-cm depth.

Table 1. Accuracy of estimates of peak diurnal warming

Wind Speed	Model	Bias (K)	STD (K)
All Winds	MW	0.20	0.52
	IR	-0.07	0.47
	Webster	0.11	0.33
	Kawai	0.24	0.41
U < 4 m/s	MW	0.13	0.58
	IR	-0.35	0.59
	Webster	0.08	0.53
	Kawai	0.03	0.63

Exact reproduction of the time of peak warming is very difficult as illustrated in Figure 3. Errors in estimating the timing of the warming add to uncertainties in the exact amount of warming present at an instant in time. A preliminary estimate of the total uncertainty in parameterized warming by hour of the day for the Gentemann parameterizations relative to actual warming at 50-cm depth is shown in Figure 4. Most noticeable is the general underestimate of warming in the IR parameterization. A portion of the bias in the IR estimates could result from the product being regressed against subsurface temperatures at depths greater than 50 cm. The warming observed at a depth of 4-5 m is less than all the predictions. An additional factor could be related to the derivation using the Reynolds OI weekly SSTs. If the Reynolds product represents a combination of day and nighttime data and not a true foundation value, the estimated warming would be less than that observed.

Further tests incorporating actual satellite retrieval references are required and will be attempted to more fully evaluate the parameterization results. These are being initiated and will be completed by the next milestone in May. From the current results only, the rms error in the estimated warming reaches near 0.5 K at peak warming and decreases at other times. This likely represents an upper bounds on the error and the further tests should yield better results.

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Webster, P. J., C. A. Clayson, and J. A. Curry, Clouds, radiation and the diurnal cycle of SST in the tropical western Pacific, *J. Clim.*, 9, 1712-1730, 1996

Task IV – Facilities – Marine Operations Funding Summary

Dr. R. Detrick, V.P. for Marine Facilities and Operations

Woods Hole Oceanographic Institution Research Vessels were provided to support the following programs for CICOR Investigators under Cooperative Agreement No. NA17RJ1233. Results of the science activities are provided by the Principle Investigator:

ECOHAB PNW: Ecology and Oceanography of Toxic Pseudo-nitzschia in the Northwest Coastal Ocean

Dr. Barbara M. Hickey

R/V Atlantis Cruise Date: (September 2004)
WHOI Project No. 37122335 and 37122347

Related NOAA Strategic Plan Goal:

Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

The scientific objective of this cruise was to study the ecology and oceanography of toxic algae Pseudo-Nitzschia. The science activities planned included CTDs, towed fish surveys, underway system and ADCP, and the release of drifters. The operations area was in the vicinity of Juan de Fuca Eddy and near the coast, latitude 46 to 48 degrees North and longitude 122 to 126 degrees West.

The scientific personnel participating on the cruise were:

Dr. Barbara Hickey, Chief Scientist, University of Washington
Dr. James Richard Postel, University of Washington
Mr. Brent Jason Leithauser, University of Washington
Ms. Katherine A. Hubbard, University of Washington – Grad. Student
Mr. Nicolaus G. Adams, National Oceanic and Atmospheric Administration – Grad. Student
Mr. Brian D. Bill, NOAA/Northwest Fisheries Science Center
Ms. Sheryl A. Day, NOAA/Northwest Fisheries Science Center
Ms. Keri Ann Baugh, NOAA/Northwest Fisheries Science Center
Ms. Jeannie M. Bush, NOAA/Northwest Fisheries Science Center
Dr. Evelyn J. Lessard, University of Washington
Mr. Michael Foy, University of Washington
Mr. M. Brady Olson, University of Washington – Grad. Student
Ms. Megan Jeanette Bernhardt, University of Washington
Mr. William Patrick Cochlan, San Francisco State University
Mr. Nicolas Christopoher Ladizinski, San Francisco State University
Mr. Julian Herndon, San Francisco State University
Dr. Mark L. Wells, University of Maine
Ms. Lisa Pickell, University of Maine – Grad. Student
Ms. Kathleen Rose Hardy, University of Maine

Ms. Margaret P. Hughes, University of California, Santa Cruz
Dr. Charles G. Trick, University of Western Ontario
Mr. Benjamin F. N. Beall, University of Western Ontario – Grad. Student
Ms. Liza Marie McClintock, University of Western Ontario – Grad. Student
Mr. Herbert G. Bergamini, University of Washington/NOAA NWFS
Mr. David Sims, Woods Hole Oceanographic Institution
Ms. Amoreena MacFadyen, University of Washington – Grad. Student
Dr. Vera L. Trainer, NOAA/Northwest Fisheries Science Center
Ms. Katherine A. Hubbard, University of Washington
Mr. Brent Leithauser, University of Washington
Ms. Jessica Ellen Schneider, San Francisco Bay National Estuarine Research Reserve
Dr. Charles G. Trick, University of Western Ontario

2005 NOAA/CICOR Progress Report

Carbon Dynamics of North American Boreal Forest Regrowth

NOAA Cooperative Agreement No. NA17RJ1223
04/01/2003-03/31/2006

Scott Goetz
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Program Manager: Kathy Tedesco NOAA/OGP Global Carbon Cycle Program

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

PROJECT BACKGROUND

This project is focused on the analysis of North American boreal forest carbon dynamics. There are several aspects to the project, including: (i) time series analysis of NOAA Advanced Very High Resolution Radiometer (AVHRR) imagery on a 10-day interval over the past two decades, (ii) estimation of biophysical attributes of the vegetation, including canopy light harvesting as it relates to photosynthesis over large areas, (iii) use of the image data, along with ancillary data sets, to drive models of carbon exchange in burned and regenerating areas, (iv) collection and analysis of field data sets to calibrate and validate the results. The data sets that we produce and the analyses that we conduct have direct relevance to the research objectives of NOAA's Climate and Global Change Program, and the USGCRP North American Carbon Program.

FISCAL YEAR 2004 PROGRESS

Work progressed in each of the focus areas outlined above, and are documented in www pages at WHRC (www.whrc.org/borealnamerica). We also made good progress on the field measurement activities in the Delta Junction region of interior Alaska (Figure 1). Our publication describing the indirect estimation of leaf area index (LAI) from handheld instruments at 34 sites in the study area was published (Hyer and Goetz, listed under publications). Our continuous field measurements of canopy light interception (Fpar) were processed for the 2003 and 2004 data set, including sensor calibrations. We now have data for the period 2001 through 2004, which was used to analyze temporal variation in light harvesting for our modeling work, and also for validation of estimates from satellite observations (Figure 2). We submitted a paper on the MODIS Fpar product validation, which was accepted for publication in a special issue on MODIS validation (Steinberg et al., under publications). The continuous canopy Fpar data set was also used in conjunction with the CO_2 flux measurements (collected by collaborator Jim Randerson at UC Irvine) to quantify the variations in efficiency of light use absorbed by the canopy for carbon sequestration. This work continues, and a publication is being prepared.

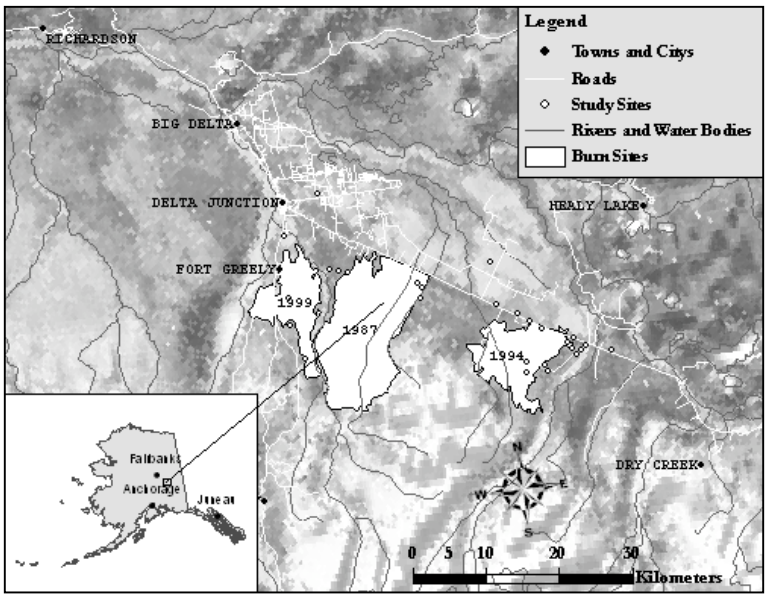


Figure 1 *The study area in interior Alaska. Individual study sites are shown.*

The time series analysis of AVHRR satellite data sets (64 km^2) was conducted across boreal North America following processing of the data sets (described in the Year 1 report). The normalized difference reflectance index (NDVI) data set was converted to estimates of the fraction of incident photosynthetically active radiation (PAR) intercepted by vegetation (i.e., Fpar), and these data were then analyzed across a wide range of burned areas across boreal North America. Regeneration from fires that burned in three episodic fire years (1981, 1989, and 1995) was characterized, including the gradual increase in canopy light harvesting (Fpar) as vegetation density and stature increased through time after fire (Figure 3). The rate of recovery varied in different fire years, even for the three episodic fire years on which we focused our analysis. Variability in the time series remaining after accounting for environmental factors, represented by the difference of burned and unburned area anomalies, increased beyond the observed post-fire recovery period which may indicate residual effects of fire disturbance over the regrowth period. As part of this analysis we also conducted a comparison of different AVHRR data sets. These results were developed into a journal publication (Fiske et al., under publications), which was submitted.

The same AVHRR data sets were used to conduct a rigorous time series and trend analysis of photosynthetic activity over the 22 year period. The trend analysis revealed that tundra vegetation experienced an increase in both peak photosynthesis and growing season length, whereas forest areas experienced a decline in photosynthetic activity between 1981 and 2003 (Figure 4). Climatic warming occurred across the entire region, but the change in the forest response indicates that long-term changes may not be predictable from initial, short-term observations. Fire disturbance has also increased with the warming but does not explain the decline in forest photosynthetic activity. This work represents an important advance at broad spatial scales and makes use of the full extent of the satellite observation record to document unique vegetation responses to climatic warming. The results are striking, unexpected, and at odds with some earlier work. A paper describing these results has been accepted (Goetz et al., under publications). A related analysis used these results to project future trends in photosynthetic activity across the region, and a paper on this analysis has also been accepted for publication (Bunn et al., see publications).

Figure 2. *Comparison of PAR cell array and MODIS F_{PAR} estimates across all sites.*

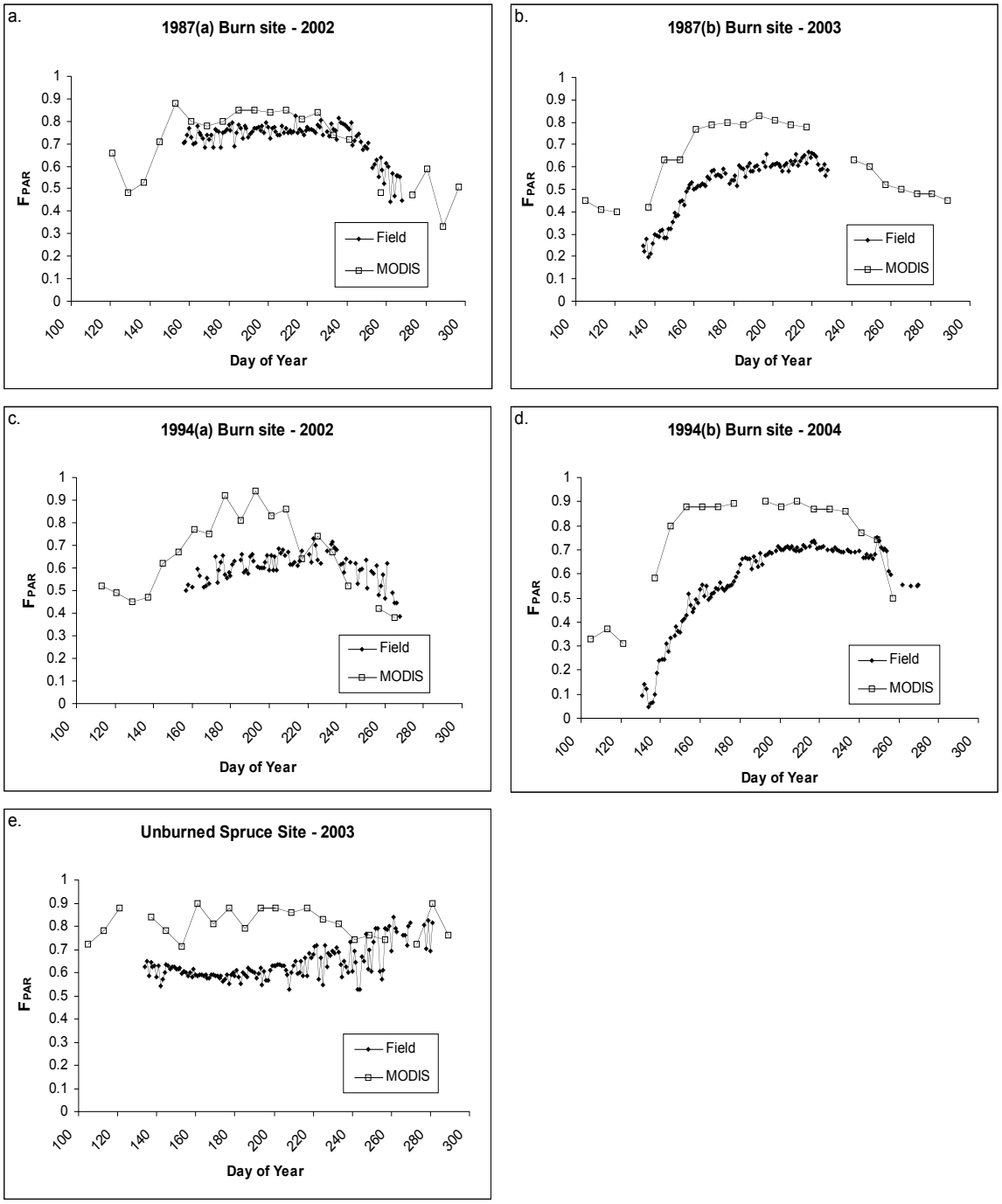


Figure 3. *Time series of AVHRR Fpar anomalies between 1981 – 2000, for all fires that occurred in 1995. The graph shows both the seasonal variation in Fpar as well as the gradual trend towards increased light interception through time as the vegetation recovers over the 20 year period (i.e., 20 years * 36 intervals per year = 720 values).*

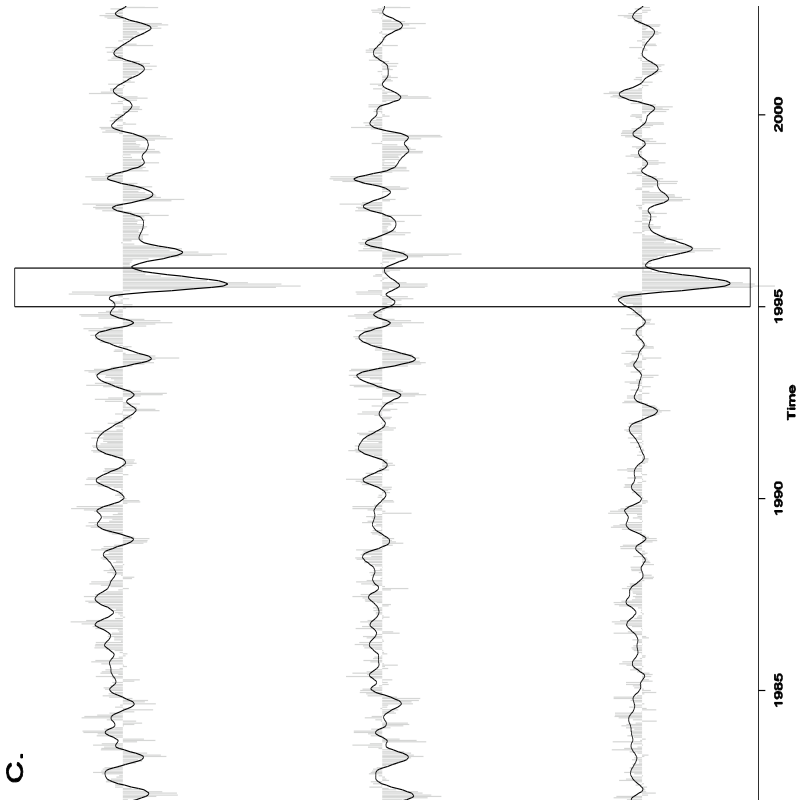
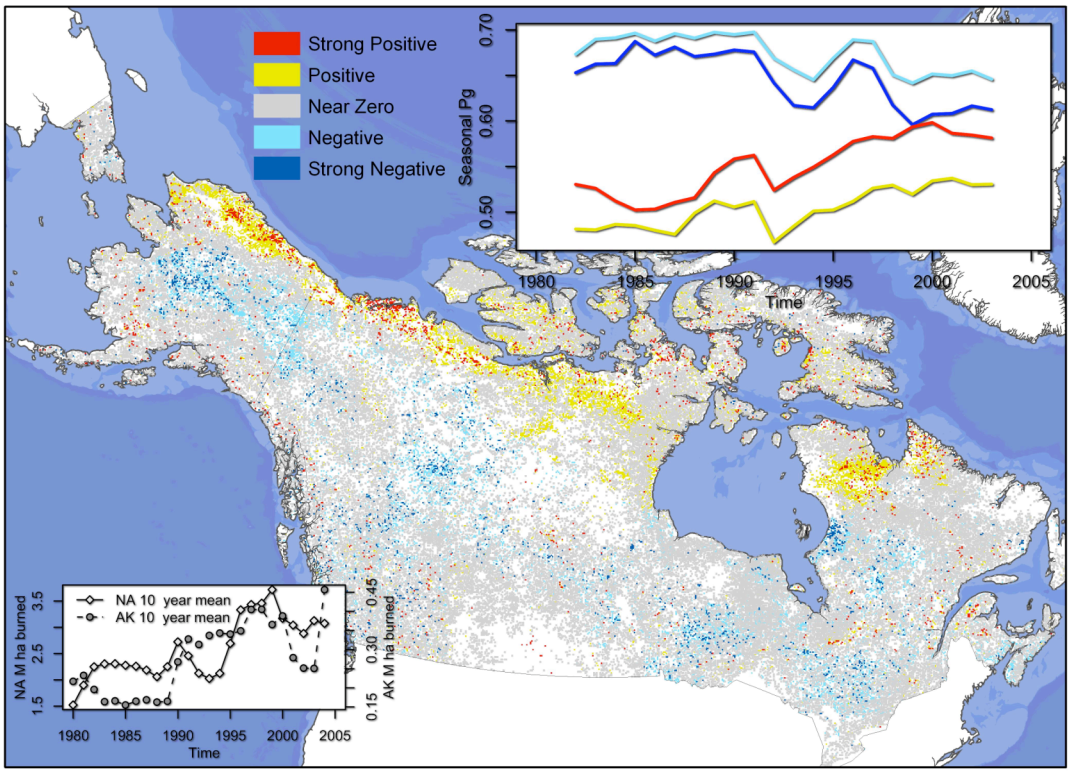


Figure 4. *Spatial distribution and magnitude of trends in photosynthetic activity across Canada and Alaska from 1982 through 2003. Colors on the inset figures correspond to those in the map. The total area burned annually across Canada and Alaska from 1980 to 2005 is shown in the bottom left.*



PUBLICATIONS

Bunn A. G., Goetz S. J. & Fiske G. J. (in press) Observed and predicted responses of plant growth to climate across Canada. *Geophysical Research Letters*.

Fiske G., Goetz S. J. & Bunn A. (submitted). Using satellite time series data sets to analyze fire disturbance and recovery in the Canadian boreal forest. *Remote Sensing of Environment*.

Goetz S. J., Steinberg D., Fiske G. & Houghton R. A. (in press) Satellite observed photosynthetic trends across boreal North America associated with climate and fire disturbance. *Proceedings of the National Academy of Sciences*. .

Hyer, E., and S. J. Goetz. 2004. Comparison and sensitivity analysis of instruments and radiometric methods for LAI estimation: assessments from a boreal forest site. *Agricultural and Forest Meteorology* 122 (3/4):157-174.

Kasischke, E. S., S. J. Goetz, M. Hansen, M. Ozdogan, J. Rogan, S. L. Ustin, and C. E. Woodcock. 2004. Temperate and Boreal Forests. Pages 147-238 *in* S. L. Ustin, editor. Remote Sensing for Natural Resource Management and Environmental Monitoring. co-published by John Wiley & Sons and American Society of Photogrammetry and Remote Sensing, Hoboken, NJ.

Steinberg D. C., Goetz S. J. & Hyer E. (in press) Validation of MODIS Fpar products in boreal forests of Alaska. *IEEE Transactions on Geoscience and Remote Sensing*.

OUTREACH ACTIVITIES

Presentations

Remote Sensing and Modeling of Boreal Forest Regrowth Dynamics (May 2004), International Boreal Forest Research Association (IBFRA) Conference, Climate-Disturbance Interactions in Boreal Forest Ecosystems, Fairbanks, Alaska.

Mapping and Monitoring Boreal Forest Regrowth Dynamics using Satellite Data Products (Dec 2004), AGU Fall Conference, San Francisco.

Thermohaline Circulation in the Atlantic and its Variability under the Energy Constraint

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 49
July 1, 2004 through June 30, 2005

Dr. Rui Xin Huang
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Program Manager: Dr. James F. Todd, NOAA

Related NOAA Strategic Plan Goal:

Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

Project Background:

The goal of this project is to study the decadal variability of the oceanic circulation, and oceanic circulation model's sensitivity under the energy constraint and the traditional buoyancy constraint.

Fiscal Year 2004 Progress:

Substantial progress has been made during the past 12 months. The most important discovery is that wind energy input to the oceans has increased greatly over the past 50 years. Wind energy input to the oceans is the most important source of mechanical energy sustaining and regulating the oceanic general circulation. Over the past 50 years, wind energy input into the oceans increased 20%, with a large increase in the Southern Ocean and a slight decline in the equatorial band. The impact to the wind-driven and thermohaline circulation of such a large variability in wind energy input can be substantial. The focus of this project is to continue to explore the dynamic impact of changes in mechanical energy input to the ocean, using both simple theoretical models and realistic oceanic general circulation models.

Numerical experiments designed for testing the difference between energy constrained models and buoyancy constrained models are currently underway.

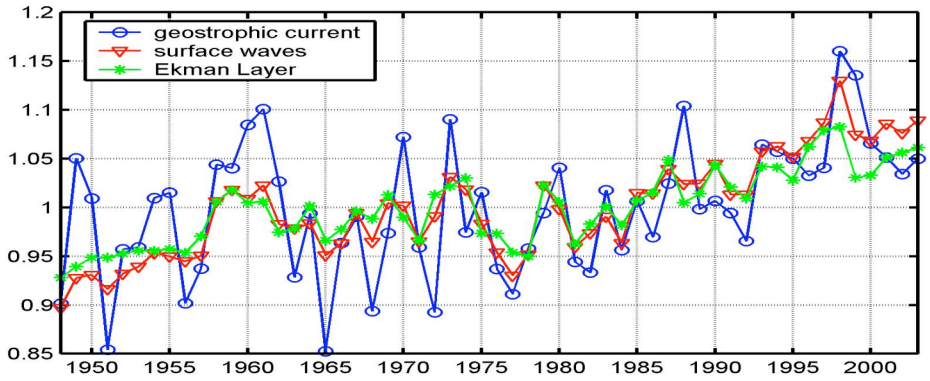

Figure 1. The time evolution of the normalized wind energy input through geostrophic current (circle), surface waves (triangle), and Ekman layer (star).

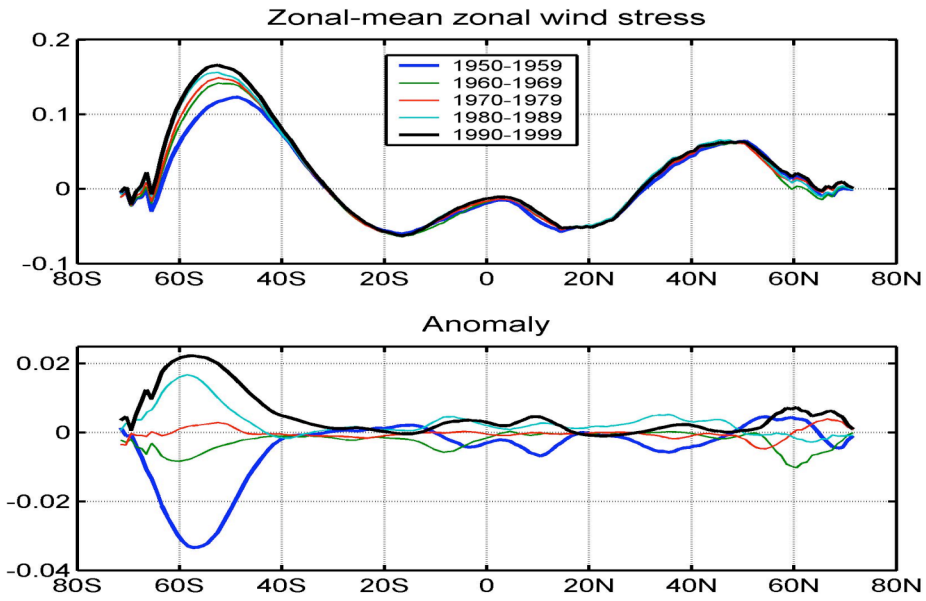

Fig. 2. Decadal-mean zonal wind stress in the world's oceans, and the deviation from the 50-year mean (in Pa), based on NCEP wind stress.

Publications:

Wang, Q. and R. X. Huang, 2005: Decadal variability of pycnocline flows from the subtropical to the equatorial Pacific. J. Phys. Oceanogr., in press.

Zhang, S. Y. and R. X. Huang, The meridional overturning circulation in an air-sea coupled 4-box model, manuscript submitted to J. Mar. Res..

R. X. Huang, W. Wang, and L. L. Liu, Decadal variability of wind energy input to the world ocean, manuscript, submitted to *Deep Sea Research II*.

Outreach Activities:

I have taught an advanced course, theory of the oceanic general circulation, for graduate students in the MIT/WHOI Joint Program. The course is offered every two years. The last time the course was offered was in the spring of 2004, and it will be offered in spring 2006.

I also worked with a summer student fellow in the summer of 2004, and her studies were related to double diffusion processes in the ocean, based on a simple box model and the traditional buoyancy constraint and the new energy constraint.

An Analysis of the Relationship between Fish Harvesting and Processing Sectors

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 43
July 1, 2004 through June 30, 2005

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PROJECT SUMMARY

This is a collaborative research between the WHOI Marine Policy Center and the NMFS Northeast Fisheries Science Center. The study is related to the CICOR theme area Coastal Ocean and Near-Shore Processes (CICOR Task II). We understand that research in this theme area is extremely broad, including issues related to fisheries management. In this project, we examine the effects of changing marine resource conditions on the coastal economy.

The commercial fisheries of the Gulf of Maine and Georges Bank are among the most important in the Nation. New Bedford, Portland, Point Judith, and Gloucester rank among the top-grossing fishing ports in the United States, and more than $692 million worth of fresh and partially processed fish was landed in New England in 2002. However, commercial landings of finfish and shellfish in New England have declined over the last fifty years from over one billion pounds in 1950 to 575 million pounds in 2002. Commercial landings of the traditional mainstay species of Atlantic cod, haddock, and yellowtail flounder have declined much more substantially as these stocks have been overfished for much of the time.

The fish-harvesting sector is linked tightly to an intricate network of onshore wholesaling, processing, and retail trade businesses. Together, the commercial fish harvesting and processing sectors in New England employ more than 16,000 people, and the annual total output value from these sectors exceeds $1.5 billion. An economic input-output analysis indicates that every $1 million increase in the sales of fish harvests leads to $1.4 million in economic impacts capturing direct, indirect and induced effects in economic sectors that both supply the fishing industry and purchase its products.

An analysis of all of the potential economic gains that could result from rebuilt fish stocks is critical. Clearly, the revenue from commercial fishing could be much higher if all of the groundfish resources were rebuilt. The economic gains might not be limited to only the harvesting sector. For example, the downstream processing sector might also grow as a consequence of rebuilt groundfish stocks. To date, however, the relationship between the harvesting and processing sectors has not been examined through a carefully designed empirical analysis.

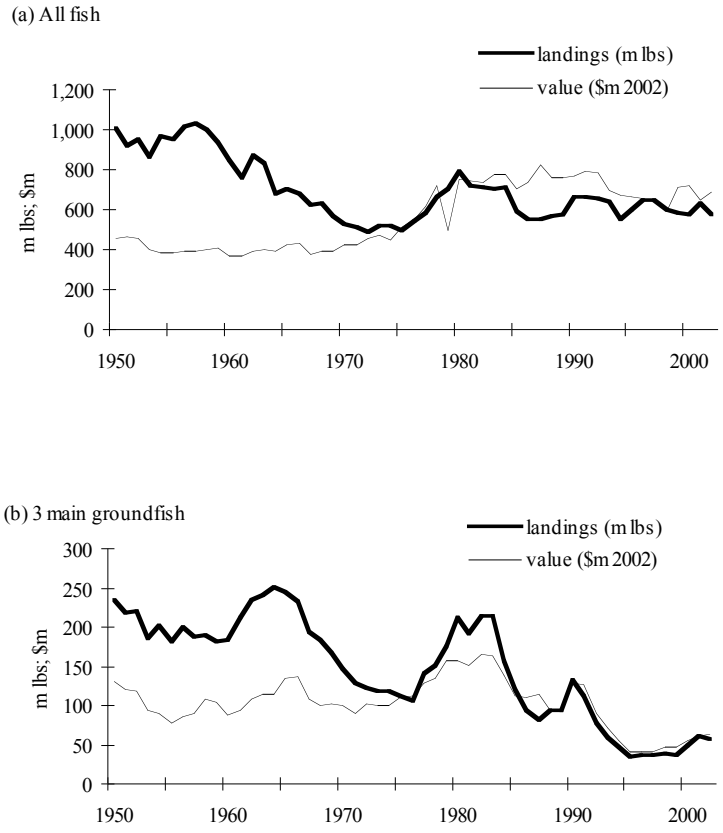


Figure. New England fish landings (million pounds) and value of landings (million dollars) for (a) all fish, including groundfish, pelagics, scallops, and lobster; and (b) the three main species of groundfish (Atlantic cod, haddock, and yellowtail flounder) from 1950 to 2002. Please note the difference in vertical scales.

The objective of this study was to develop a characterization of the relationship between fish harvesting and processing in New England. The characterization should enable improved assessment of the economic growth in the processing sector due to rebuilding of groundfish stocks. The hypothesis that economic output from the New England processing sector is not related to changes in the supply of fish from local harvests is the focus of the study. If this hypothesis is rejected, then the economic ramifications of low resource levels may have been and continue to be deeper and more widespread than is currently appreciated. Further, the relationship between the output from the fish processing sector and fish imports is examined.

The study results suggest that output from the fish processing sector is jointly determined by local fish landings and fish imports. The level of imports is an important factor in the management of fish processors. Local landings were found to *Granger-cause* processing in several cases, implying that past resource conditions indeed affected present processing output. In contrast, no significant causality was found between processing and landings. Given the low abundance stock condition during the study period, one would not expect processing to drive harvest.

A unidirectional causality was also found from processing to imports: processors import more fish when local landings decline. All identified Granger causalities in the study existed only at

aggregate (all species) level, suggesting that the cause and effect relationship is weak at the individual species level. This is due to inter-species substitution as well as substitution among different raw fish suppliers (e.g., local landings versus imports).

The study findings indicate that firms in the fish processing sector optimize their business operations over multiple species and multiple supply sources. Although an increase in local fish landings generally leads to an expanded seafood processing sector, the interaction may be complex, due to various substitution effects. A clearer understanding of these substitution effects will improve assessment of the economic gains accruing from rebuilding fisheries in New England.

PUBLICATION

Jin, D., P. Hoagland and E. Thunberg. 2004. An analysis of the relationship between fish harvesting and processing sectors in New England. *Marine Resource Economics*, Submitted.

INTERACTION WITH NOAA

This is a collaborative research between the WHOI Marine Policy Center (MPC) and the NMFS Northeast Fisheries Science Center. Di Jin and Porter Hoagland of MPC worked closely with Dr. Eric Thunberg of the Social Sciences Branch at the Northeast Fisheries Science Center (Woods Hole) throughout the project.

2005 NOAA/CICOR Progress Report

Variations in Oceanic CO_2 Concentration, Transport and Divergence in the Atlantic

NOAA Cooperative Agreement No. NA17RJ1223, sub-point 26

Dr. Alison M. Macdonald and Dr. John M. Toole, Co-Principal Investigators
Woods Hole Oceanographic Institution

Program Manager: Kathy Tedesco, NOAA

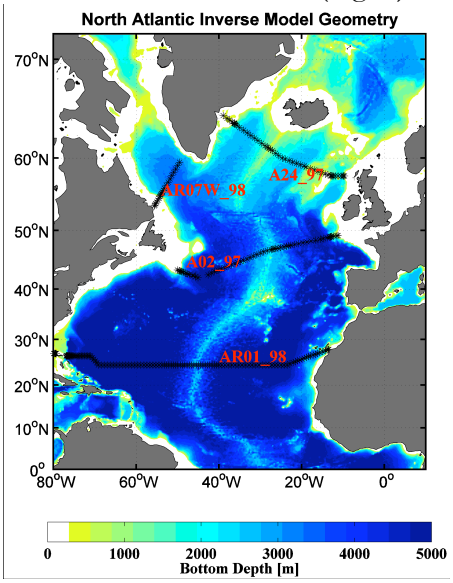
Related NOAA Strategic Plan Goal:

Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

The NOAA/CICOR grant supports 50% of the work to create a WOCE-era Atlantic dataset to be used in a box model inversion to study the concentration, transport and divergence of total inorganic and anthropogenic carbon and possible temporal variations in these quantities. The other 50% of funding comes from NSF grant OCE-223421.

PROJECT SUMMARY AND HIGHLIGHTS

The Atlantic's central role in the global thermohaline circulation suggests that this basin should be an important laboratory for understanding the ocean carbon cycle and possible temporal variations in that cycle. Thus, many of the newly available one-time and repeat WOCE/OACES/JGOFS hydrographic transects which included carbon measurements were performed in the Atlantic. Our project is designed to synthesize these high-resolution, zonal and meridional data into an inverse box model capable of providing an estimate of the three dimensional circulation of the full basin which can then be used to investigate the uptake, transport and storage of total inorganic carbon (TIC), anthropogenic carbon (C_{anth}) and pre-industrial (*i.e.* prior to human intervention) carbon (C_{pre}). We are currently working on the development of two different models: a simple two-box version of the North Atlantic (Fig. 1a) and a full Atlantic model (Fig1b).



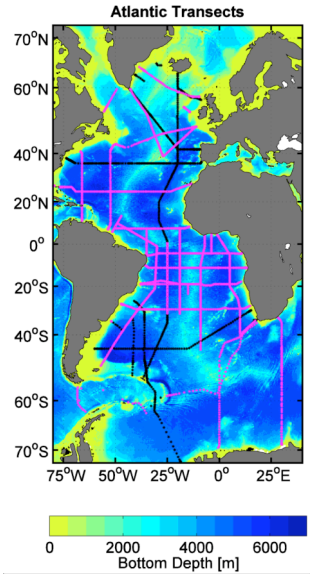


Figure 1. (a) (Left Panel) Location of the stations being used in the North Atlantic model. Names indicate the year of the cruise and the WOCE designation. (b) (Right Panel) Location of the hydrographic station data currently available to the Atlantic model. Black symbols indicate that we have no TIC measurements for the section,. Pink indicates that we do. The cruises include lines with WOCE designations: A01W, A01E, A03, A05-A17, A20-A2, SO4A and I06.

Recent studies which have looked at the role the North Atlantic is

playing in the uptake of CO_2, including our own 1998-1992 comparison of observed carbon fields and fluxes across 24°N, have suggested that there may be substantial uptake and/or storage of CO_2 in this basin. The North Atlantic model defined by the observations (Fig. 1a) and a basic set physical constraints suggests a TIC flux across 24°N (Fig. 2) which is not significantly different from the previous estimate using the 1998 24°N data alone. As expected and more importantly, however, the uncertainties have been reduced from those found using the

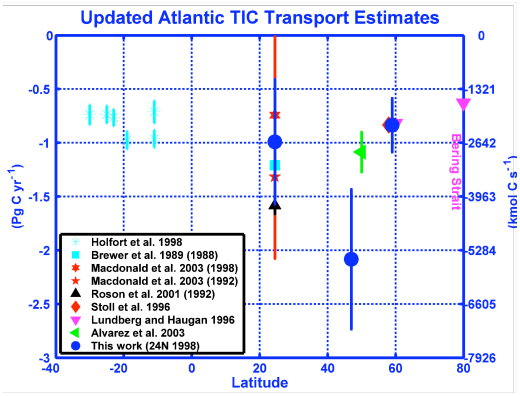


Figure 2: Atlantic TIC transport estimates as a function of latitude from various independent studies, including the North Atlantic model discussed here. Net flux through Bering Strait and the Arctic are included in all the estimates.

single line model. At 57°N, our estimate of net TIC transport and uncertainty is surprisingly similar to previous findings given that different datasets and different analysis techniques were employed. At 47°N, the model produced the interesting result of a very strong southward transport of TIC (2.1±0.7 $PgCyr^{-1}$) implying, if one does not consider storage, a strong uptake of carbon to the north of 47°N (further north than originally expected), and outgassing within the subtropics which may be (depending on which 24°N value one chooses to believe) nearly as strong. This model also suggests a relatively weak northward transport of C_{anth} across 47°N. Combining these results with Takahashi's (2002) CO_2 air/sea exchange estimates and instead estimating storage terms as the residual, suggests that today's uptake of carbon is spread over a greater region within the North Atlantic than pre-industrially, but that today both the uptake and outgassing are weaker.

To better understand these results the circulation was separated into overturning and horizontal components. This comparison suggested that unlike latitudes to the north and south in which the overturning circulation cell dominates and controls the magnitude of the southward transport of TIC, at 47°N there is a large horizontal component to the circulation of TIC concentrated in the western basin in the region of the North Atlantic Current and recirculation. In the coming year these results will be compared to those from a set of data coming from the early 1990s.

Through our subcontract with D. Hansell we have also analyzed the dissolved organic carbon (DOC) observed along 24°N in 1998. The net northward DOC flux (3.3±1.9 Tmol C yr^{-1}), taken along with estimates from the literature, suggests that the North Atlantic basin is slightly net heterotrophic, but overall is metabolically balanced, i.e. local production is balanced by local remineralization.

We now have in hand most of the 1990's Atlantic long line datasets (Fig. 2a). Initially, this model is made up of about 40 boxes. Although the present extent of the data set does not permit a full Atlantic temporal comparison, the full Atlantic model should provide insight into a number of questions:

- What is the character (strength & structure) of the Atlantic circulation as observed through the WOCE dataset?
- Based on this circulation, what are the spatial patterns and magnitude of the horizontal and vertical transports of TIC and Canth within the Atlantic? Which water masses are responsible for these transports. How do these values compare to estimates of pre-industrial transports?
- Where within the basin does storage occur?
- What is the character and magnitude of the air-sea exchange of CO_2?

Publications and presentations to date derived partially, if not wholly from NOAA grant 37122326 include:

Hansell. D. A., H. W. Ducklow , A. M. Macdonald and M. O'Neil Baringer, 2004, Metabolic poise in the North Atlantic Ocean diagnosed from organic matter transports, *Limnology and Oceanography*, **49**, 1084–1094.

Macdonald A. M., M. O'Neil Baringer, R. Wanninkhof, K. Lee and D. W. R. Wallace, 2003, A 1998–1992 comparison of inorganic carbon and its transport across 24.5°N in the Atlantic. *Deep Sea Research II*, **50**, 3041–3064.

Macdonald, A. M., North Atlantic CO_2 transport and divergence, Invited talk, EGU Meeting, Nice, France, 2004.

Also presented at the Cooperative Institute for Climate and Ocean Research (CICOR) Executive Board Meeting, WHOI, May, 2004.

Extended version given at the Wednesday PO lunch seminar in October 2004.

Macdonald, A. M., Oceanic CO_2 Transport, Divergence and Air/Sea Exchange in the North Atlantic, 2nd Annual CARINA general meeting and open science conference, 2003. Also presented at the NSF NACP PI Meeting, May 2003.

Macdonald, A. M., M. O'Neil Baringer, D. W. R. Wallace and R. Wanninkhof, Carbon Transport at 24.5°N in the Atlantic, Presented by R. Wanninkhof at the CIMAS external review, 2003.

Macdonald, A. M., CO_2 transport and divergence in the North Atlantic, Seminar at AOML in Miami, March 2005.

2005 NOAA/CICOR Progress Report

Assessment of Air-Sea CO_2 Exchange Rates in the World's Oceans Using Bomb ^{14}C Inventories Derived from WOCE Global Survey

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 50
July 1, 2004 through June 30, 2005

Dr. T.-H. Peng[1], R. Wanninkhof[1], R. Key[2] and A. M. Macdonald[3], Co-PIs.
[1]NOAA, AOML, [2]Princeton, [3]Woods Hole Oceanographic Institution

Program Manager: Kathy Tedesco, NOAA

This project follows the outline for the CICOR Theme "The Oceans Participation in Climate and Climate Variability". A. Macdonald's portion of the project is administered through CICOR

PROJECT SUMMARY AND HIGHLIGHTS

One of the main goals of NOAA's contribution to the U.S. Interagency Carbon Cycle Science Program, documenting the fate of the approximately 6 Pg of CO_2 which is being put into the atmosphere every year through human activities, requires quantification of the spatial patterns and variability of carbon sources and sinks throughout the globe. Likewise, quantifying the exchange of CO_2 between the atmosphere and ocean is critical to our understanding of the rate of atmospheric increase and where anthropogenic carbon goes. The inventory of ocean bomb-radiocarbon ($^{14}C^*$) can provide a constraint on estimates of CO_2 exchange rates as it is directly related to the exchange process. Until recently the only estimates of $^{14}C^*$ inventory were based upon a relatively sparse dataset (Broecker et al. 1985) provided by the GEOSECS (1970's), Pacific NORPAX(1979) and North Atlantic TTO (1980's) programs. The newly available radiocarbon ($\Delta^{14}C$) measurements collected during and just prior to the period of WOCE represent a 10-fold increase in size of the database. This project will use these data to achieve the following goals:

- To determine the global air-sea CO_2 exchange rates based on the bomb ^{14}C distribution observed during the 1990's WOCE program
- To re-evaluate air-sea CO_2 exchange rates based on the bomb ^{14}C distribution estimated from the 1970's GEOSECS program using an improved potential alkalinity method for separating natural (pre-nuclear) radiocarbon from the observed, $\Delta^{14}C$ values.
- To use an inverse box model formulation to derive air-sea CO_2 exchange rates from the oceanic ^{14}C distribution, ocean circulation and mixing. This third goal is the CICOR component to be performed by A. Macdonald.

During this first year of the project the main focus has been on separating the natural radiocarbon values from the observed, $\Delta^{14}C$ values so that distribution and inventories of $^{14}C^*$ from both the GEOSECS and WOCE programs are available. The CICOR component of the project has taken this database (Fig. 1) and has begun reformatting it for use within existing Pacific and Atlantic Ocean inverse models. The use of inverse modeling will explicitly allow for advection in the analysis of the oceanic radiocarbon distribution. During the third week in

March 2005, Peng, Wanninkhof and Macdonald will meet to discuss the next steps in the project, including detailing how the radiocarbon data should be used within the inverse model setup. Two difficulties must be overcome: the lack of $\Delta^{14}C$ observations on zonal lines in the Pacific (Fig. 1) and the paucity of WOCE-era $\Delta^{14}C$ observations along transects in the Atlantic. These issues may or may not be best solved through the use of data mapping.

No publications or presentations have yet come out of this grant, although A. Macdonald will present some results from the Atlantic inversion effort while visiting AOML to meet with co-pi's this March.

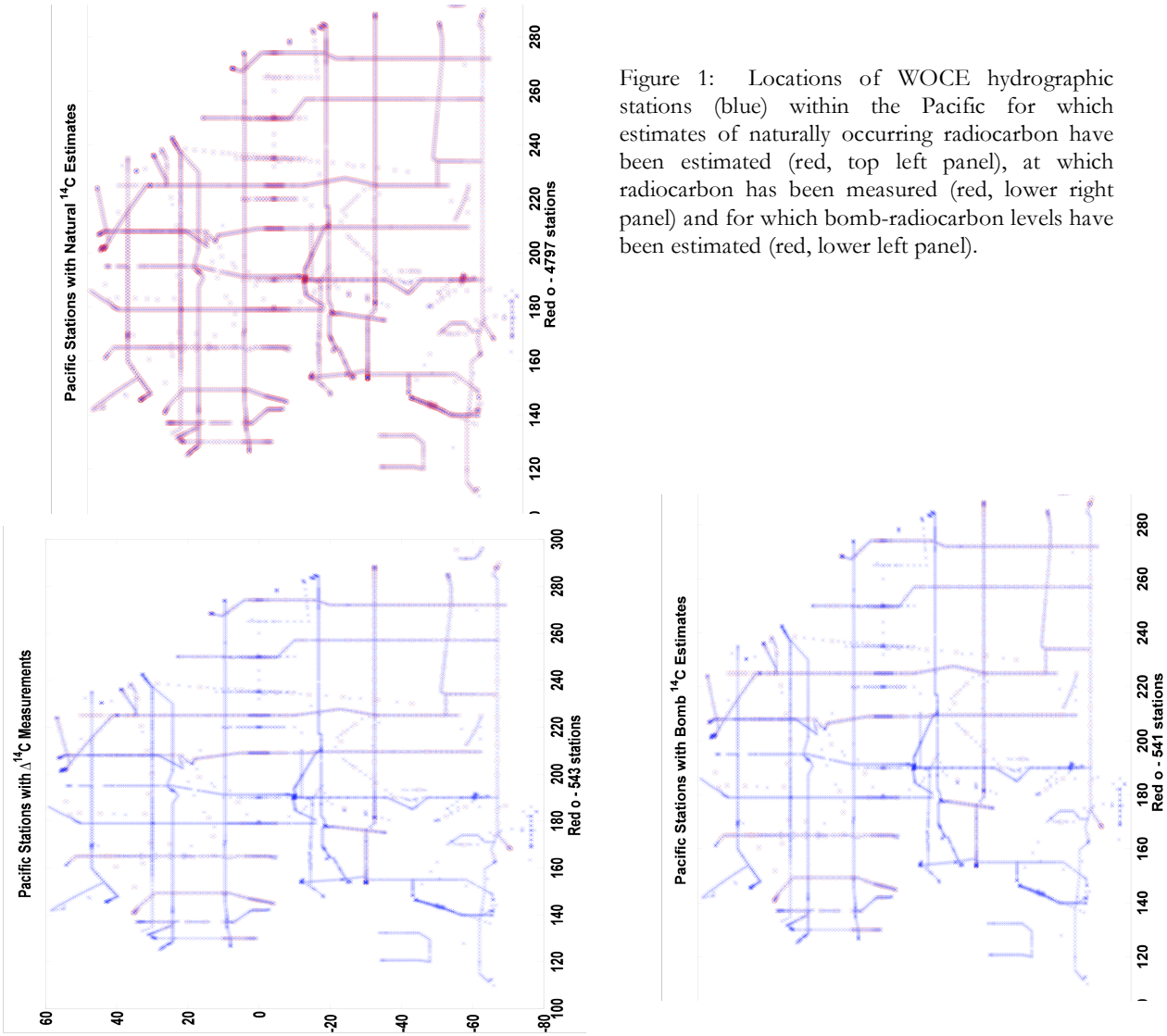


Figure 1: Locations of WOCE hydrographic stations (blue) within the Pacific for which estimates of naturally occurring radiocarbon have been estimated (red, top left panel), at which radiocarbon has been measured (red, lower right panel) and for which bomb-radiocarbon levels have been estimated (red, lower left panel).

2005 NOAA/CICOR Progress Report

The Argo Float Program

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 04
July 1, 2004 through June 30, 2005

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Program Manager: Steve Piotrowicz, NOAA/OAR

Related NOAA Strategic Plan Goal: Goal 2 – Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond.

The goal of the Argo float program is to have 3000 profiling floats reporting profiles of temperature and salinity on a 10-day cycle covering the global ocean. Once this coverage has been achieved the further objective is to sustain this array indefinitely. The US is expected to provide half the array and the WHOI component of the Argo float program that has been funded for phase II through CICOR represents approximately 15% of the array. The duration of phase II is 5 years, starting in July 2001.

The Argo float program was designed to provide data for a number of different usages. These range from real-time analyses by operational centers to high precision analyses by climate scientists to investigate decadal climate signals. This breadth has placed an extraordinary demand on both the performance of the instruments and on the infrastructure to process the data so that the data is distributed in a timely manner to real-time users and subjected to stringent quality control to provide a high-quality data set that will exponentially increase coverage and quantity of data available to construct ocean climatologies.

In the first year of phase II WHOI was slated to provide 80 floats. In subsequent years, this increased to 105 floats per year. At the outset of the Argo float program, it was decided to use a next generation of profiling float, rather than the design used for the World Ocean Circulation Experiment. This choice was made to increase the reliability and mission duration of the floats to achieve the stated goals of the Argo float program. WHOI chose to collaborate with the Instrument Development Group at Scripps Institution of Oceanography in the development of the SOLO float. Unfortunately, the development of both U.S. designed floats suffered significant birthing pains such that the initial failure rate was unacceptable. This led to a hiatus in float deployments and a continued delay in the manufacture and deployment of floats. This year, 2005, we expect to finally reduce the backlog in float manufacture.

Although the design of the floats has finally matured, we continue to make significant improvements in the design to insure the goal of a mean 4-year lifetime, depth coverage to 2000 m globally, improved sensor stability, and enhanced vertical resolution to provide data as

comparable as possible to ship-based measurements. We have also strived to develop multiple vendors of floats and sensors to insure competitive pricing and high quality. To this end, WHOI has worked with Falmouth Scientific to incorporate their CTD into the SOLO float design as well as using the Seabird CTD in our floats. The bulk of the floats presently use the Argos satellite communications system to transmit their data back to shore. This 1970's technology severely limits the data transmission bandwidth and forces us to dedicate nearly 50% of the battery power to data communications. To achieve significant increase in the vertical sampling rate and resolution of the data, we initially incorporated Global Positioning System navigation and ORBCOMM satellite communications into a small fraction of the WHOI floats. We were able to demonstrate that we could achieve an improvement of an order of magnitude in vertical sampling, an order of magnitude increase in data resolution, and reduction of nearly two orders of magnitude in battery power using this two-way communications. This communications protocol was also migrated to the Spray glider. Unfortunately, there appeared to be a subtle design flaw in the match between the ORBCOMM GPS receiver and the antenna design. For the Spray glider, we migrated to a GPS/Iridium short burst messaging system that has proven to be quite robust. We are presently in the final redesign of a new low-cost GPS/Iridium antenna and are finalizing the migration of the ORBCOMM data format to the Iridium short burst messaging.
We expect to start deploying a limited number of GPS/Iridium floats in the summer of 2005 to prove the design, and plan to eventually migrate entirely to this design. In addition to the improved bandwidth, these floats will also spend only a few minutes on the sea surface that will improve conductivity sensor stability. Finally, we have implemented two-way communications so that we can alter the float mission parameters to react to the local ocean environment and the status of the float.

The Argos float program also represented a significant change in the way that the WHOI float operations group operates. In the past, we operated in a research mode where the scheduling of tasks reflected the occasional research cruise. We now operate in a much more operational fashion where cost savings is carefully considered and the documentation of production is more carefully controlled so that float failures can be more easily investigated. Manufacturing of floats now is a nearly continuous process where we now have an inventory of floats so that we can respond to deployment opportunities, most of which are carried out in conjunction with AOML. We believe that we have now transformed the WHOI float group into an operational mode where high quality sustained measurements can be routinely made.

We have also been intimately involved in the development and implementation of the delayed-mode quality control of the Argo float salinity data. This procedure, first described by Wong, Johnson, and Owens (2003) uses climatological databases to document and correct the long-term drift of the salinity sensors on Argo floats. This system also continues to evolve. At a recent Argo float delayed mode workshop, a number of improvements to the technique were suggested. These improvements include: interpolation of the climatology to the observed float profiles rather than to interpolated float values, more selective choice of depths for the calibration comparisons, and a piece-wise linear fit to the conductivity drift that more correctly models the physical model of the sensor drift. We are presently implementing these improvements and will make this improved system available to the international Argo float community.

Finally, through involvement in the International Argo Steering team and the Global Ocean Data Assimilation Experiment (GODAE), we have help to develop the Argo float program and insure that the data is available for real-time data assimilation. The Argo float program is one of the vanguard programs involved in the evolving Global Ocean Observing System and the CICOR funded WHOI contribution is a significant part of this effort.

2005 NOAA/CICOR Progress Report

Flow of Pacific water through the Western Chukchi: Dynamics and biological implications

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 46
July 1, 2004 through June 30, 2005

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Program Manager: John Calder NOAA

Related NOAA Strategic Plan Goal:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

PROJECT BACKGROUND

In summer 2004 the Russian icebreaker *Khromov* carried out the inaugural cruise of the Russia-US Long-term Census of the Arctic (RUSALCA) program. RUSALCA resulted from the 2003 Memorandum of understanding for World Ocean and Polar Regions Studies between NOAA and the Russian Academy of Sciences. The three-leg expedition was a great success, during which US and Russian scientists carried out an array of multidisciplinary projects aimed at furthering our understanding of climate change in the Arctic. Leg 2 focused on the region from Bering Strait northward into the Chukchi Sea, and our part of the hydrographic component of this leg consisted of a detailed survey of the flow through Herald Canyon (Figure 1). This is the first time that the canyon, which lies in Russian territorial waters, has been sampled at high cross-stream resolution, enabling us to resolve fully the currents and water masses. The survey was done using a conductivity/temperature/depth (CTD) package with the addition of dissolved oxygen, turbidity, fluorescence, a lowered acoustic Doppler current profiler, and a video plankton recorder for measuring zooplankton and particle (marine snow) content in the water.

Pacific water enters the Arctic through Bering Strait and is largely steered through the Chukchi Sea by the topography of the shelf. In particular, the two canyons on either side of the Chukchi Sea−Barrow canyon in the east and Herald canyon in the west−tend to concentrate the flow before it reaches the shelfbreak. Presently we know very little about the flow through Herald canyon, although this branch contains a significant amount of the transport of the Pacific water, and carries most of the nutrient load into the Arctic. The topography of the canyon is such that hydraulic control may be active, which in turn could influence the downstream entrainment of the flow as well as its ability to form eddies. These are the kind of things we need to know in order to determine the ultimate fate of the Pacific water when it reaches the open Arctic, and the associated implications for climate change.

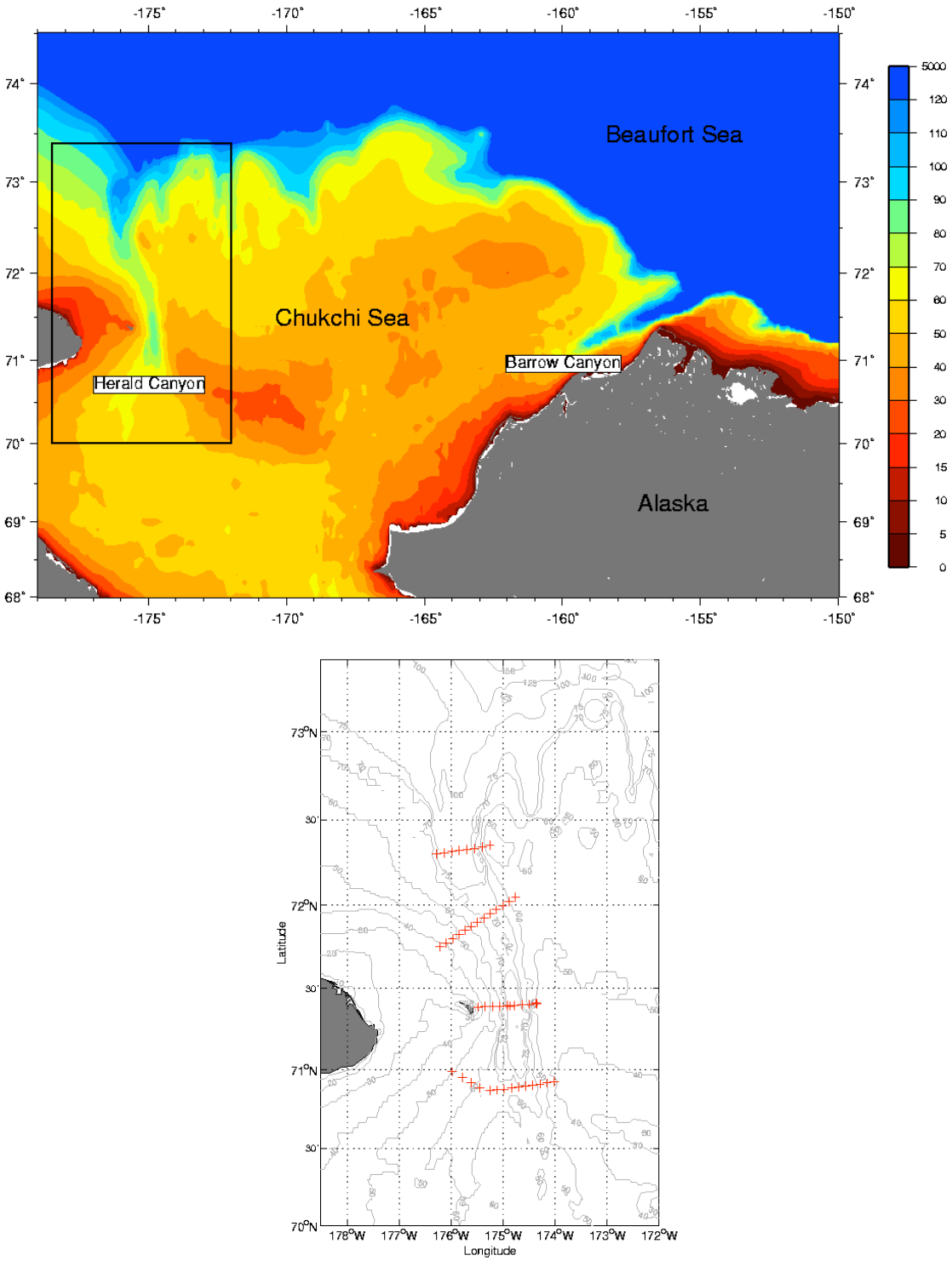


Figure 1: (a) Bottom topography of the Chukchi Sea showing the two canyons that help steer the flow from Bering Strait. The depth is in meters (key on the right). (b) Hydrographic stations (red crosses) comprising the RUSALCA Herald Canyon survey. The survey took roughly three days to complete.

FISCAL YEAR 2004 PROGRESS

The final processing, calibration, and de-spiking of the RUSALCA CTD data set were completed, and a data report was written and distributed to the PIs in the RUSALCA group. The processed data, station profile plots, and vertical section plots of the data were made available to the group on a website. The lowered ADCP velocity data are still being processed, and will soon be complete.

The analysis of the CTD data are now underway. Figure 2 shows the vertical sections of potential temperature, turbidity, and fluorescence from the crossing at the head of Herald canyon. On the western side of the canyon one sees cold, dense winter water (magenta color) above the bottom, adjacent to warm summertime Bering water on the eastern side of the canyon. Presumably both of these water masses are flowing northward. The turbidity and fluorescence distributions show a strong plume emanating from the bottom beneath the summer water (near station 54) while the fluorescence shows a distinct plume surrounding the winter water. These features may arise in part due to the dynamics of the flow through the canyon−for instance bottom boundary layer detachment or convergence and downwelling of the jet. We will pursue these ideas in the coming months, and describe the overall adjustment of the Pacific water, including the ramifications for the chemistry and biology of this region.

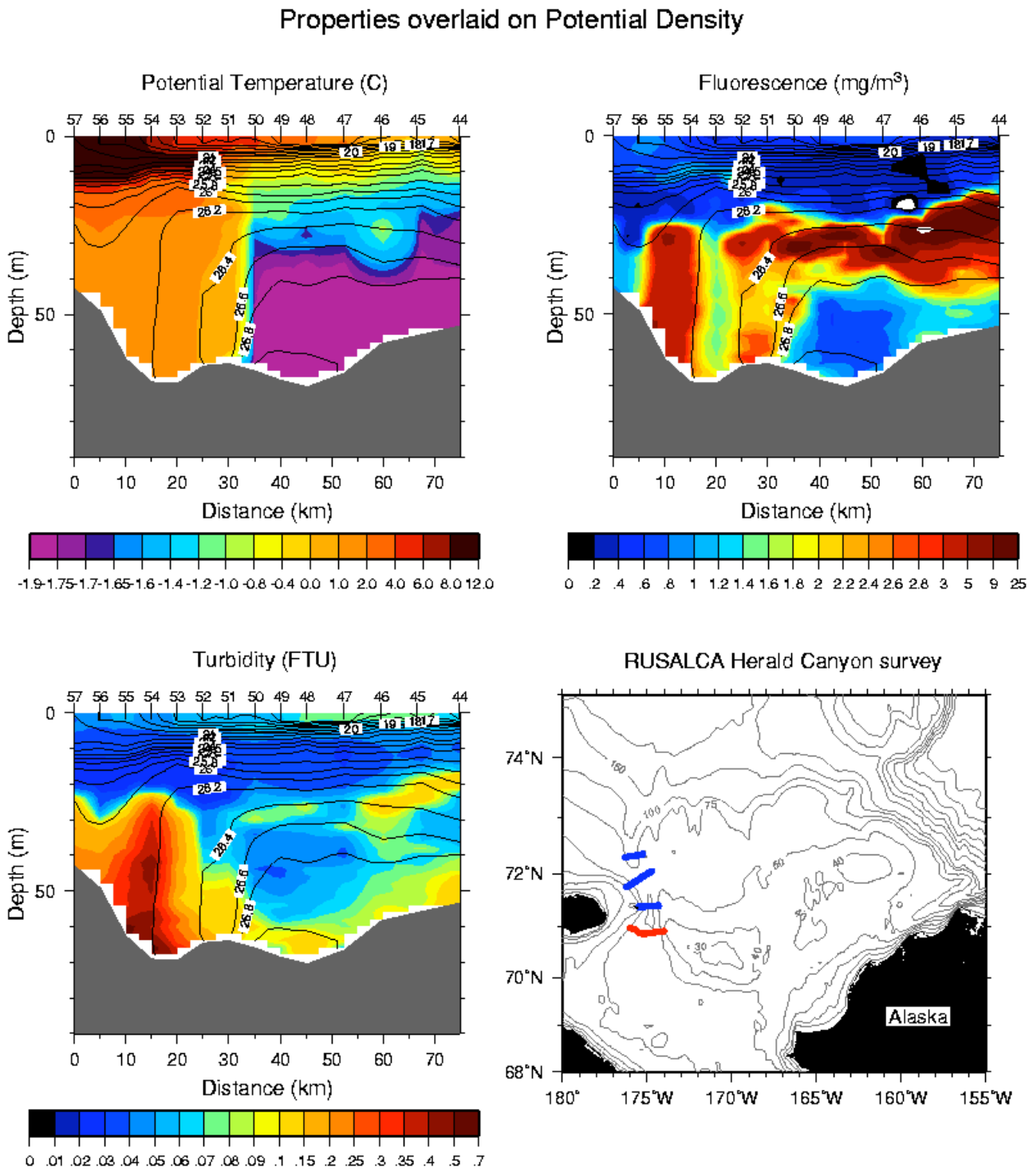


Figure 2: Vertical sections of properties (color) at the head of Herald Canyon, overlaid on potential density (contours, kgm^{-3}). The location of the section is marked in red on the lower right panel.

Constructing end-to-end budgets for shelf ecosystems

GLOBEC GEORGES BANK ENERGY

GLOBEC 01 MODEL/DATA ANALYSIS

NOAA Grant - NA17J1223 sub-points 22 and 55
05/01/2004-06/30/2005

Dr. J. Steele and Dr. A. Beet (with J. Bisagni, J. Collie, D. Gifford, M Sieracki, B. Sullivan)
Woods Hole Oceanographic Institution

Program Manager: Dr. Elizabeth Turner, NOAA Coastal Ocean Program

Related NOAA Strategic Plan Goal:

Goal #1: Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

SUMMARY

Oceanographic regimes on the continental shelf display a great range in the time scales of physical exchange, biochemical processes and trophic transfers, Fig. 1. The close surface-to-seabed physical coupling at intermediate scales –weeks to months – means that the open ocean paradigm of a relatively autonomous microbial loop is inadequate. But purely top-down trophic depictions are insufficient to constrain a system subject to physical forcing as well as fishing. These processes are found on most continental shelves but are particularly important on Georges Bank where the weeks-to-months regime is dominant in relative area and in productivity, Fig. 2.

We have generated budgets for the microbial food web, Fig. 3a, for three physical regimes, Fig. 2 and for three seasons –spring, summer and winter. The calculations show that vertical mixing and lateral exchange between the three regimes are important for zooplankton production as well as for nutrient input. Also benthic suspension feeders (anchored plankton) are a critical pathway for transfers to higher trophic levels. Estimates of production by mesozooplankton, benthic suspension feeders and deposit feeders, Fig. 4, provide input to an upper trophic food web, Fig. 3b. The diets of commercial fish populations are used to calculate food requirements in three categories, planktivores, benthivores and piscivores, for four decades or stanzas, between which there were major changes in the fish communities.

Comparisons of food requirements with inputs from the microbial web, Fig. 5, Fig. 6, indicate that (1) piscivore needs are relatively constant, even though there are major species shifts, and these needs can be met by the production of pelagic juvenile pre-recruits. (2) Averaged over the four decades, the needs of the planktivores account for 80% of zooplankton production, but recent large increases in pelagic fish stocks would appear to leave no food source for invertebrate predators such as "jellies" (3) benthivorous fish requirements are a small fraction, 5-

15%, of available food, implying that other components including meiobenthos andinvertebrate predators such as crabs or shrimps, must play a large role in the food web.

DISCUSSION

The basic premise is that top-down changes in fish populations are constrained by the output from the lower components so that, for example, detritus is not a free variable. Rather we would expect variations in nutrient supply to propagate through the system as changes in productivity at all trophic levels. The lack of change in the piscivorous fish requirements would suggest that bottom-up effects are not evident over the four stanzas on Georges Bank.

There is much interest in the declines in top predators such as sharks, swordfish etc. It is of interest that our calculated requirements of piscivorous fish not only change little, but are estimated to consume effectively all of their major food source, the pre-recruits. This is in spite of a major switch in species composition from cod and hake to dogfish.

Unlike the piscivores, the estimates for pelagic fish, including the pre-recruits, vary significantly over the four stanzas, in response to major increases in populations of herring and mackerel; to the point where requirement exceeds supply. It should be noted that the adult populations are migratory and spend part of their annual cycle away from the Bank. It is difficult to estimate the invertebrate predators on the mesozooplankton, particularly the "jellies" such as ctenophores, but populations of these predators sampled in 1995-1999 would be expected to have significant food requirements at certain seasons. Given these uncertainties, the general conclusion is that the pelagic fish populations are likely to be limited by food supply and, possibly by competition from other predators.

The story is very different for benthivorous fish over the last few decades. There would appear to be a large fraction of superfluous production in the benthic invertebrates as depicted here by a simple two-stage food chain. One solution is to envisage a more complicated web with a significant role for meiobenthos as in the North Sea (Steele, 1974), or with several predatory stages. In other areas such as Newfoundland and the North Sea, declines in benthivorous fish are linked to increases in commercial catches of crabs, shrimp and lobsters. The obvious question is – how much could production be increased? The **apparent** answer, from these calculations is to 14 $gC.m^{-2}.year^{-1}$ (or about 0.6 million tonnes fish biomass for the whole Bank). **But only if** (1) they are not piscivorous and eat, solely, suspension and deposit feeders, (2) they can displace any invertebrate benthic predators and (3) there is no increase in the pre-recruit populations.

CONCLUSIONS

These results require estimates of a great range and diversity of parameters. Even more important, they depend on assumptions about processes such as pre-recruit dynamics, where we have little direct evidence. Nevertheless, the results seem intuitively reasonable and are in line with calculations for fish stocks in a similar ecosystem, the North Sea. The underlying postulate, that each of the stanzas can be described by a linear steady state budget, is patently inadequate. It needs to be complemented by some process of punctuated equilibrium for switching between stanzas. Such "regime shifts" (Collie et al, 2004; Steele and Collie, 2005) will be incorporated in a fuller description of these systems.

The main use of ecosystem budgets is to elucidate the problems in quantifying the interactions between external forcing and internal structure. This analysis for Georges Bank illustrates the difficulties but also demonstrates the necessity of having end-to-end food web calculations. No single top-down or bottom-up process determines the observed patterns. There may be decimation of top predators but first order piscivores can switch successfully to other species, albeit less commercially attractive ones. Certain major fish components such as plankton feeders may be limited by the basic productivity of the ecosystem, while there is surplus production of benthos. Management of the diversity of fishery resources requires an approach based on a full appreciation of the whole food web.

PUBLICATION

Steele, J. H. and Collie, J. S. 2005. Functional diversity and stability of coastal ecosystems. *In* The Sea, Vol. 13 (eds. Robinson, A.R., Brink, K.): 783-817.

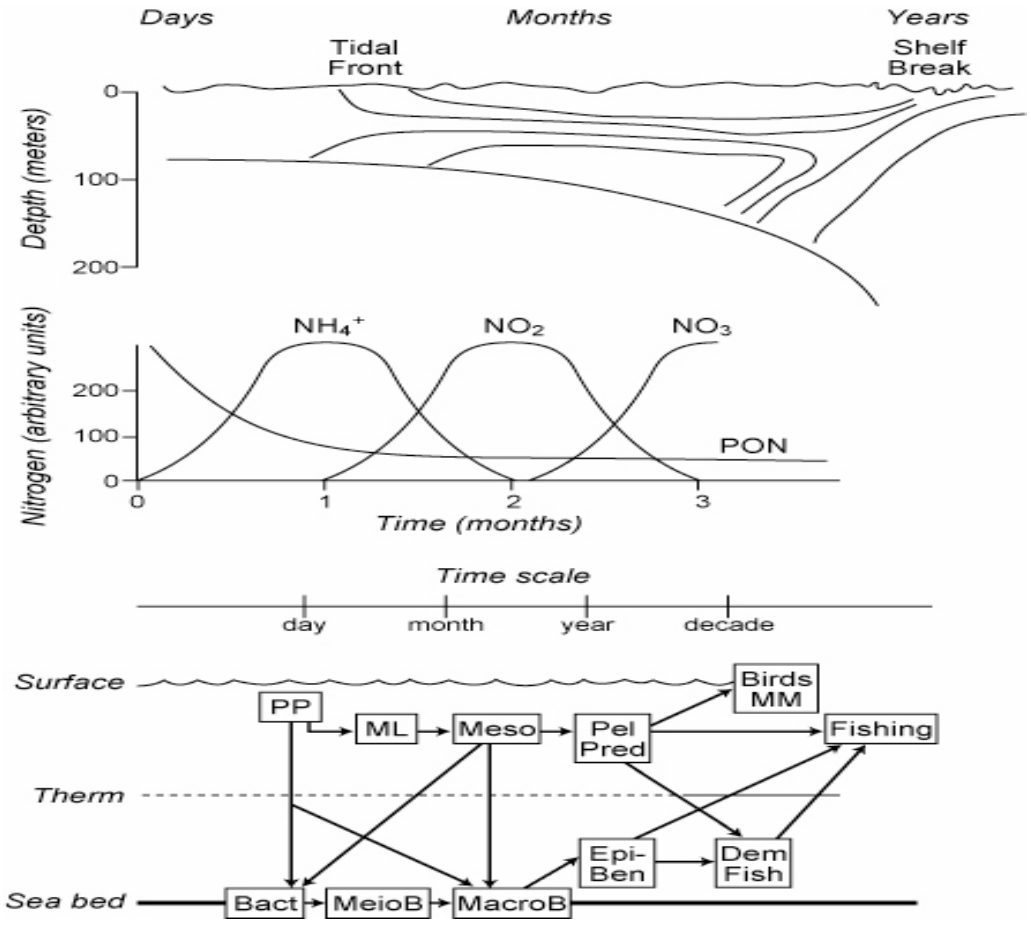
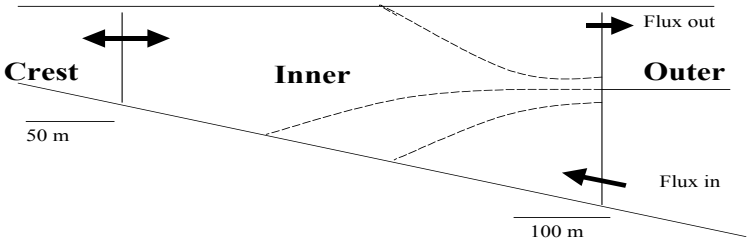


Figure1. Coastal processes: (a) time scales – days to years - of top-to-bottom physical mixing are related to frontal systems determined in part by depth and tidal currents, (b) regeneration of organic matter appears to have time scales of weeks to months (Karl and Michaels 2001), (c) food web expressed in terms of time scales (from Steele and Collie, 2005)



79	180	91	New Prodn
455	310	265	Net Prodn
0.17	0.58	0.34	f-ratio

Figure 2. Schematic representation of three mixing regimes – well mixed, sporadically mixed and stratified - on Georges Bank New production data from Bisagni (2003, unpublished); net production O'Reilly et al (1987) and the f-ratio shows the difference from oceanic regimes and the importance of calculating new or export production directly for food web calculations.

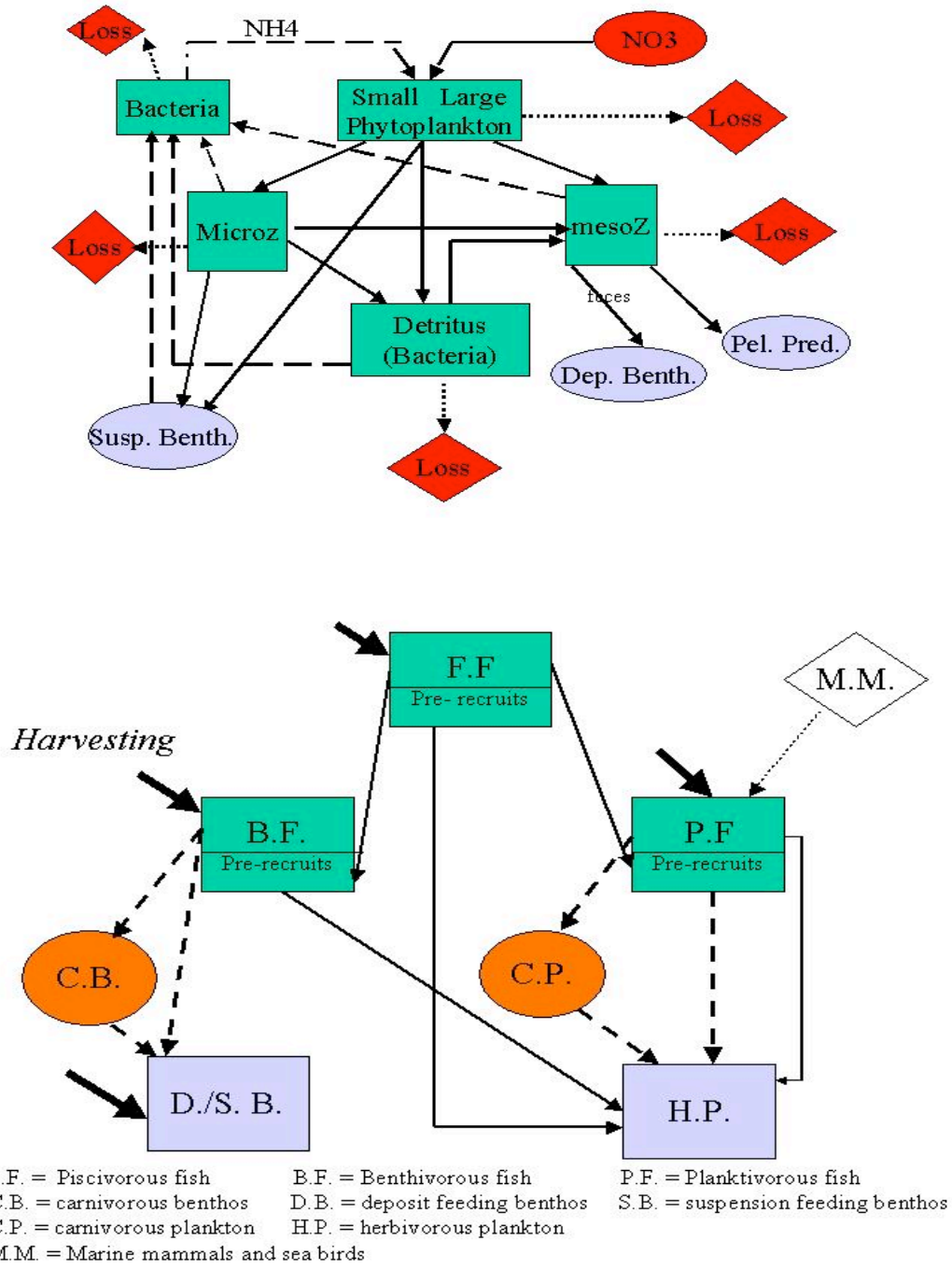


Figure 3. Top. The microbial food web based on nitrogen budgeting. Rectangles, components of the web: Ovals, input of NO3 and exports to upper trophic levels: Diamonds, physical losses due to mixing and advection: Dashed lines, recycling through bacteria and NH4. Bottom. The upper web. Solid arrows denote estimated food requirements from fish diets. Dashed arrows are the unknown links. Inputs to D./S.B. and H.P. are from the microbial food web. Marine mammals are not considered significant here .

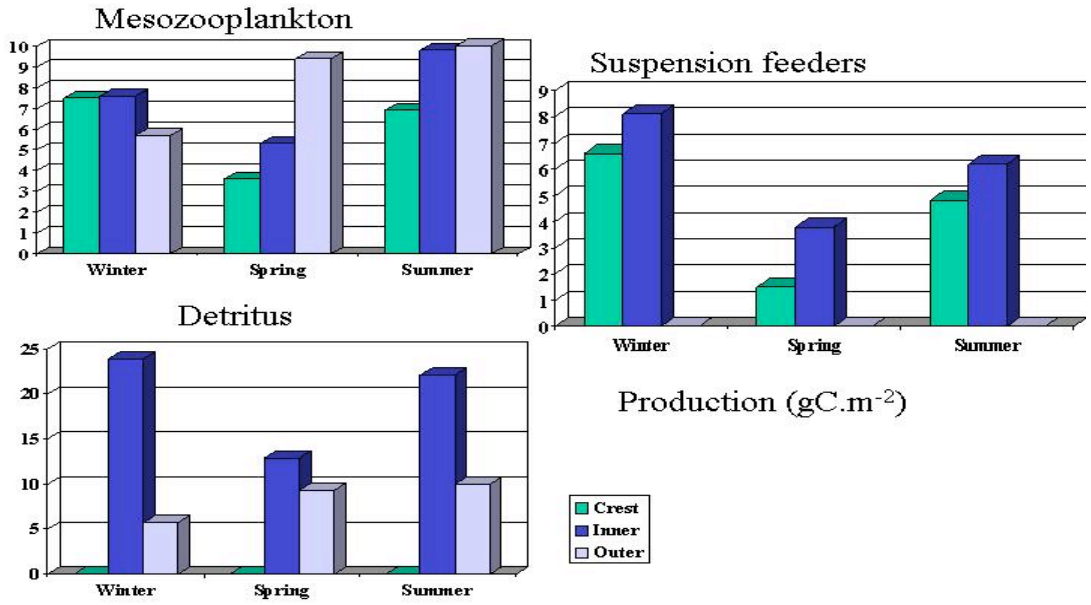


Figure 4. The production in the microbial food web that is exported to higher trophic levels. We assume that there is no suspension feeding in the Outer region and no deposit feeding on the Crest.

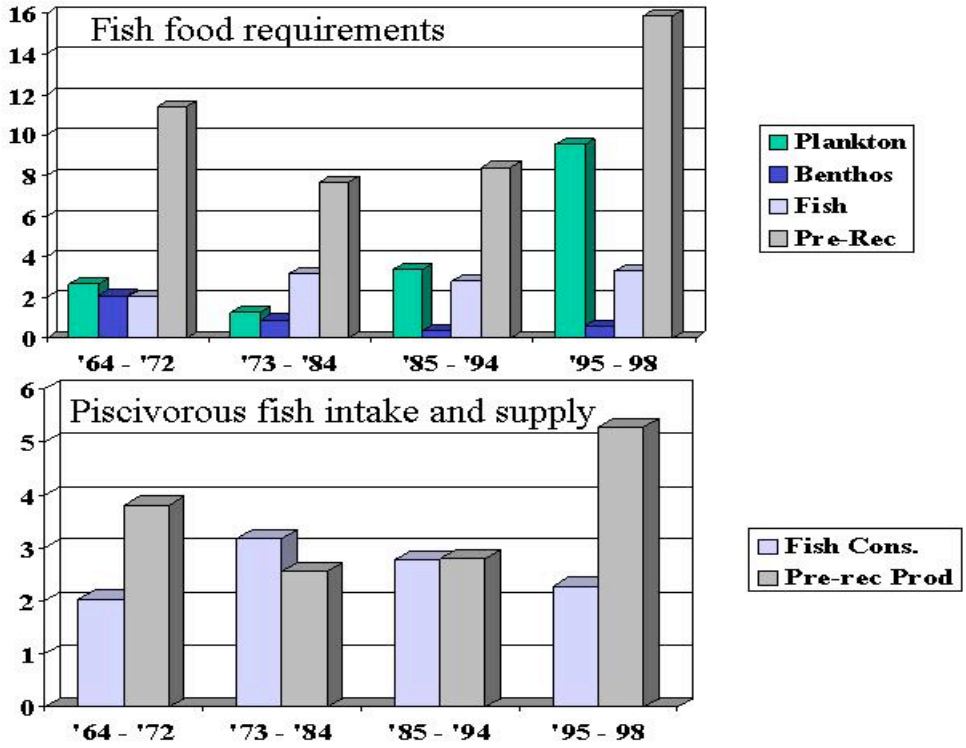


Figure 5 Top: The food requirements of plankton, benthos and fish eating fish; plus those of the pre-recruits. .Bottom: A comparison of piscivorous fish food requirement with their assumed intake - pre-recruit production

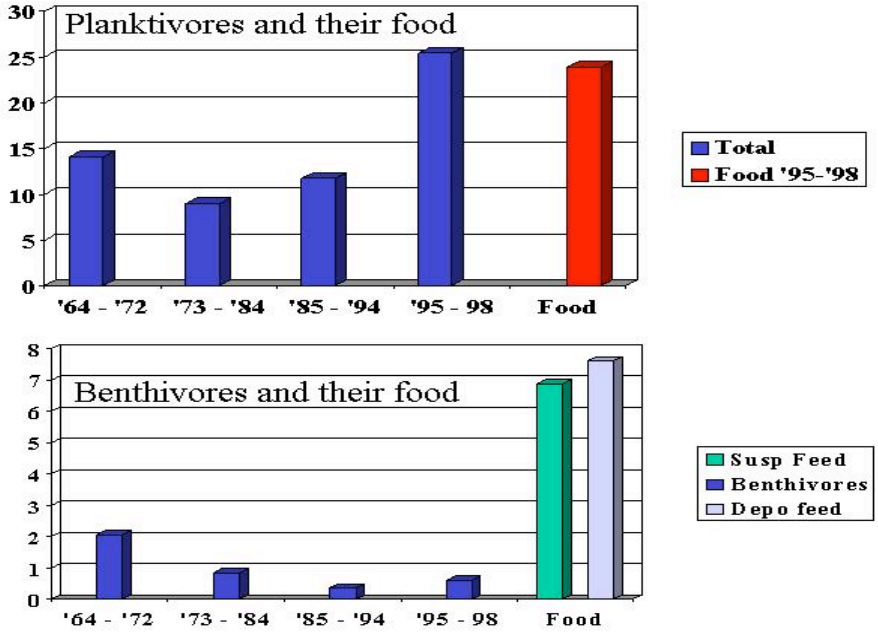


Figure 7. Top: A comparison of planktivorous fish requirements, including pre-recruits, with mesozooplankton food production. Bottom: Comparison of benthivorous fish requirements with the two sources. Suspension feeders production has been reduced by 2.0 $gC.m^{-2}.year^{-1}$ to allow for scallop harvesting. Progress Report

2005 NOAA/CICOR Progress Report

GLOBEC Target Species: Interactions with Top Trophic Levels

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 33
July 1, 2004 through June 30, 2005

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NOAA Center for Sponsored Coastal Ocean Research

Related NOAA Strategic Plan Goal:

Goal 1 – Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management.

Goal 2 – Understand climate variability and change to enhance society's ability to plan and respond

PRJOJECT SUMMARY:

The goal of Global Ocean Ecosystems Dynamics (GLOBEC) is to understand and predict how marine species respond to global climate change. Among the uncertainties in a warmer global climate is the extent to which upwelling will increase or decrease in specific boundary current systems, such as the California Current System, and consequently affect the productivity and community structure and function. Our interdisciplinary research, as part of the Northeast Pacific GLOBEC (NEP GLOBEC) program, assists NOAA with Strategic Plan Goals 1 and 2 (above) to analyze top trophic levels (i.e., marine mammals and seabirds) in the northern California Current System (CCS) relative to mid-trophic levels and bio-physical coupling in the system. Among our objectives is to develop predictive bio-physical models of mammal and seabird occurrence patterns in order to improve our understanding of the mechanisms involved in ecosystem change, thus to improve predictability and management of living marine resources important to coastal communities.

Analyses of the coupled bio-physical data sets for two process cruises in the northern CCS during spring and summer 2000 have been completed (Tynan et al. 2005, Ainley et al. 2005). We have examined the correspondence between cross-shelf and along-shelf variation in physical forcing, oceanographic features, productivity, prey fields (as represented by acoustic backscatter at 4 frequencies), and cetacean and seabird occurrence patterns. Occurrence patterns of cetaceans and densities of seabirds were compared with hydrographic and ecological variables (e.g., sea surface temperature, sea surface salinity, thermocline depth, halocline depth, chlorophyll maximum, distance to the shoreward edge of the upwelling front, distance to the center of the equatorward jet, and acoustic backscatter at 38, 120, 200 and 420 kHz) derived

from instruments on a towed undulating array (SeaSoar) and a four-frequency bioacoustic system. Using a multiple logistic regression model, 60.2% and 94.4% of the variation in occurrence patterns of humpback whales *Megaptera novaeangliae* during late spring and summer, respectively, were explained. That humpbacks occurred in regions of highest abundance of Pacific sardine *Sardinops sagax*, high densities of euphausiids, and the highest catch of juvenile salmon (Figure 1) suggests that whales were responding to a cascade of trophic dynamics enhanced by flow-topography interactions and the strong upwelling signature at a submarine bank and off Cape Blanco (Tynan et al. 2005). The percentage of variation in occurrence patterns explained by our logistic regression models for four species of cetacean (humpback whale, Pacific white-sided dolphin *Lagenorhynchus obliquidens*, Dall's porpoise *Phocoenoides dalli*, and harbor porpoise *Phocoena phocoena*) are among the highest ever achieved, and are likely a result of the concurrent acquisition of fine-scale oceanographic data with the cetacean survey data, as well a result of predator knowledge of the system (Tynan et al. 2005). In the multiple regression models for distributions of 12 species of seabirds, the most important explanatory variables (among 14 initially included in each model) were distance to the upwelling–derived frontal features (center and edge of the coastal jet, and an abrupt, inshore temperature gradient), sea surface salinity, acoustic backscatter representing various sizes of prey, and chlorophyll maximum (Ainley et al. 2005).

Our analyses of cetacean and seabird distributions in the northern CCS show the importance of the alongshore upwelling front, position of the coastal jet, vertically integrated backscatter at specific frequencies (i.e., prey), and the chlorophyll maximum to resolve top trophic distributions (Figure 1 reproduced from Tynan et al., 2005). Processes important to top trophic levels include flow-topography interactions between the upwelling front and jet with bottom topography at a submarine bank and at a large coastal promontory on the eastern boundary current circulation (see Figure 2 reproduced from Tynan et al., 2005). Enhanced mesoscale variability (e.g. strong meanders) in the system also improved our ability to explain the occurrence patterns for some species (i.e. Dall's porpoise). The responses of cetaceans and seabirds to biophysical processes in the northern California Current upwelling system are both seasonally and spatially specific. Results of these analyses provide the framework for further development of predictive biophysical models of top predator occurrence in the California Current System. This research therefore assists in the protection and management of coastal resources through ecosystem-based management. In addition, by examining the influence of upwelling dynamics and circulation on occurrence patterns of top predators, this research contributes to our understanding of the effects of climate variability on the northern California Current ecosystem. Continued synthesis and integration of numerous data sets collected during NEP GLOBEC will help elucidate the influence of climate on the physics and biology of the California Current marine food web.

ONLINE STATUS OF DATA

Cetacean and bird data from the two GLOBEC NEP NCC cruises of 2000 have been posted on the U.S. GLOBEC website http://globec.whoi.edu/jg/dir/globec/nep. Data for 2002 will be posted soon. Robert Groman (Woods Hole Oceanographic Institution) manages the data pages for U.S. GLOBEC. Additional information about the NEP GLOBEC and U.S. National GLOBEC programs is available at: http://globec.oce.orst.edu/groups/nep and http://www.usglobec.org

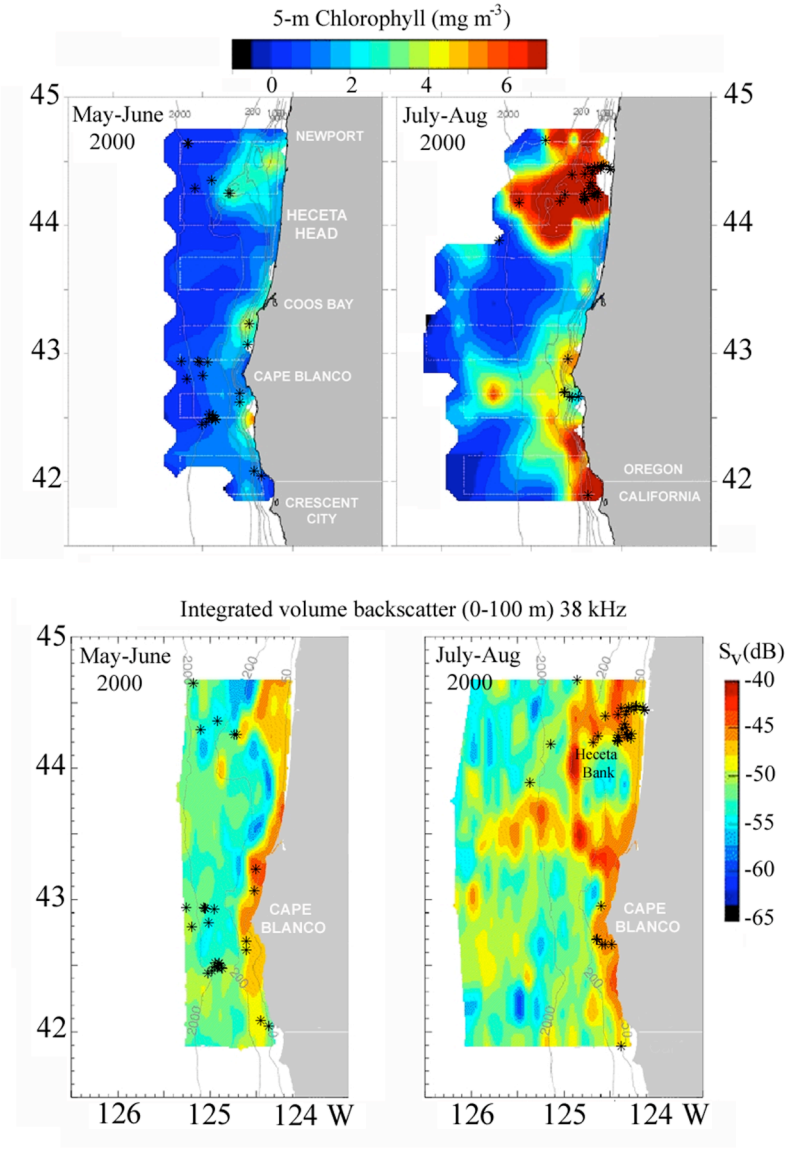

Figure 1. The correspondence of humpback whale sightings (*) with surface (5 m) chlorophyll and volume acoustic backscatter at 38 kHz integrated over 0-100 m, during May-June and July-August 2000. A higher (less negative) value of integrated backscatter (dB) indicates greater scattering at that frequency. The correspondence between humpback whales and higher chlorophyll and higher backscatter at 38 kHz is evident near Cape Blanco during spring and on Heceta Bank during the summer upwelling season. Figure 1 is reproduced from Tynan et al. (2005).

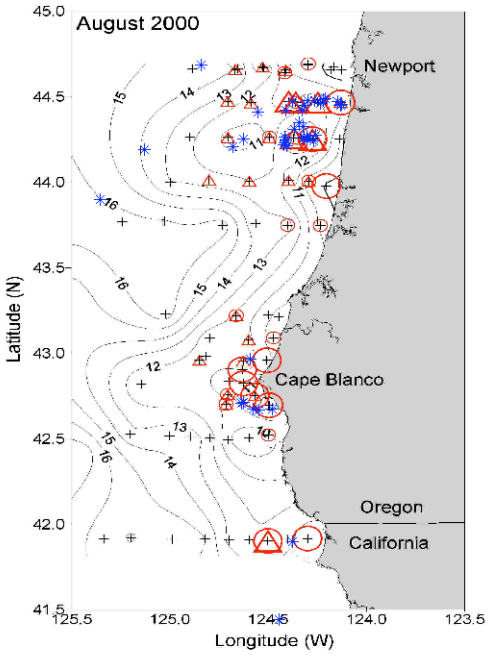

Figure 2. The correspondence of humpback whale *Megaptera novaeangliae* sightings (blue stars) overlaid on catch distribution for juvenile coho *Oncorhynchus kisutch* (red triangles) and juvenile chinook salmon *O. tshawytscha* (red circles) from surface trawls (catch data courtesy of R. Brodeur, NOAA) conducted during August 2000. Catch data is overlaid on surface temperature contours. The size of triangles and circles is proportional to the size of the catch: smaller symbols represent catch of 1 to 5 salmon; larger symbols represent catch of 6 to 150 salmon. Plus signs are stations where no salmon were caught. The correspondence between humpback whales and regions of higher juvenile salmon abundance (near a submarine bank, Heceta Bank, and off Cape Blanco) is clear. Figure 2 is reproduced from Tynan et al. (2005).

PUBLICATIONS:

Tynan, C.T., D.G. Ainley, J.A. Barth, T.J. Cowles, S.D. Pierce, L.B. Spear. 2005. Cetacean distributions relative to ocean processes in the northern California Current System. *Deep-Sea Research Part II* 52: 145-167. Contribution Number 483 of the U.S. GLOBEC program; WHOI Contribution Number 11035.

Ainley, D.G., L. B. Spear, C.T. Tynan, J.A. Barth, S.D. Pierce, R.G. Ford, T.J. Cowles. 2005. Physical and biological variables affecting seabird distributions during the upwelling season of the northern California Current. *Deep-Sea Research Part II* 52: 123-143. Contribution Number 438 of the U.S. GLOBEC program.

PRESENTATIONS OF RESEARCH:

During 2003 – 2005, more than 14 presentations of the research were given at national and international conferences, US GLOBEC meetings, and universities.

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., Peterson, W.T., Brodeur, R., Batchelder, H., Strub, T., Thomas, A., 2003. 'Mesoscale distributions of cetaceans and seabirds relative to oceanographic processes in the northern California Current: A GLOBEC study, 2000 and 2002.' ONR International Field Office, Joint Planning Meeting US, UK, NATO, London, January 21, 2003

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Cetacean distributions relative to ocean processes in the northern California Current System: A GLOBEC study.' Eastern Pacific Ocean Conference (EPOC), Sept. 24-27, 2003.

Ainley, D.G., Spear, L.B., Tynan, C.T., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Factors affecting the spatial patterns of occurrence of seabirds in the northern California Current waters, spring and summer, 2000'. Eastern Pacific Ocean Conference (EPOC), Sept. 24-27, 2003, poster

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Cetacean distributions relative to ocean processes in the northern California Current System: A GLOBEC study.' Invited seminar: WHOI Biology Department Seminar, October 2, 2003

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System, an upwelling boundary current system.' Invited talk: ONR – Effects of Sound on the Marine Environment (ESME), Woods Hole, October 21, 2003

Tynan, C.T., 'Developing predictive biophysical models of cetacean distribution in the California Current System.' Invited seminar: Old Dominion University, Center for Coastal Physical Oceanography, November 3, 2003

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System.' Invited Science Talk, US GLOBEC SSC, National Academy of Sciences, Woods Hole, November 6, 2003

Ainley, D.G., L.B. Spear, C.T. Tynan. 'Occurrence patterns of seabirds in the California Current'. Pacific Seabird Group, Cabo San Jose, Mexico, January 2004.

Tynan, C.T. and R. D. Brodeur, Session Chairs for OS21J, 'Understanding the Physical and Biological Coupling of Marine Population Dynamics: Higher Trophic Levels in the Northeastern Pacific, January 26-30, 2004 AGU Ocean Sciences, Portland, Oregon.

Tynan, C.T., D.G. Ainley, L.B. Spear, J.A. Barth, T.J. Cowles, S.D. Pierce, 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System', January 26-30, 2004 AGU Ocean Sciences, Portland, Oregon; participation in GLOBEC SI meeting and synthesis planning workshop following AGU.

Ainley, D.G., L.B. Spear, C.T. Tynan. 'Occurrence patterns of seabirds in the California Current'. ASLO, Honolulu HI, February 16-20, 2004.

Tynan, C.T. 'Toward predictive biophysical models of cetacean occurrence patterns in the California Current System, an upwelling boundary current system'. Requested presentation for Mr. Donald Schregardus, Deputy Assistant of the Navy (Environment) (DASNE) and CDR Karen Kohanowich, Ocean Resources Advisor, during visit to WHOI, March 9, 2004.

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Biotic and abiotic cross-shelf transport: comparing carbon transport by humpback whales with carbon transport in offshore jets of the California Current System', Eastern Pacific Ocean Conference (EPOC), Sept. 22-26, 2004, poster.

Tynan, C.T., Ainley, D.G., Spear, L.B., Barth, J.A., Cowles, T.J., Pierce, S.D., 'Biotic and abiotic cross-shelf transport: comparing carbon transport by humpback whales with carbon transport in offshore jets of the California Current System', GLOBEC SI Meeting, Corvallis, Oregon, November 15-16, 2004, poster.

U.S. Research Vessel Surface Meteorology Data Assembly Center

NOAA Cooperative Agreement No. NA17RJ1223
July 1, 2004 through June 30, 2005

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Program Manager: Michael Johnson, NOAA/OCO

Related NOAA Strategic Plan Goals:
Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.
Goal 3. Serve society's needs for weather and water information.

PROJECT BACKGROUND

The central activity of the U.S. Research Vessel Surface Meteorology Data Assembly Center (DAC) is the continued development of the Shipboard Automated Meteorological and Oceanographic System (SAMOS) initiative (http://samos.coaps.fsu.edu/). The SAMOS initiative focuses on improving the quality of and access to surface marine meteorological and oceanographic data collected *in-situ* by automated instrumentation on research and merchant vessels. The DAC activities focus primarily on NOAA Strategic Plan Goals 2 and 3 by providing high quality weather and near surface ocean data for use in validating satellite products, global air-sea flux analyses, and model fields.

The DAC was established at the Florida State University specifically to coordinate the collection, quality evaluation, distribution, and future archival of SAMOS data. SAMOS are typically some form of a computerized data logging system that continuously records navigation (ship's position, course, speed, and heading), meteorological (winds, air temperature, pressure, moisture, rainfall, and radiation), and near ocean surface (sea temperature and salinity) parameters while the vessel is at sea. Measurements are recorded at high-temporal sampling rates (typically 1 minute or less). The DAC is collaborating with the Woods Hole Oceanographic Institution (WHOI) and Scripps Institution of Oceanography (SIO) to design a ship-to-shore-to-user data pathway for U.S. research vessel SAMOS data. In the past, the data flowed from ship to shore only in a delayed-mode with a 3 month to 2 year lag between collection and availability to the user community. The new vision will support data transmission from each ship to the DAC on a daily basis. A "preliminary" version of the SAMOS data will be available soon after receipt by the DAC. The preliminary data will have undergone common formatting, metadata

enhancement, and automated quality control. Visual inspection and further scientific quality control will result in a "research" quality SAMOS product. Plans are being developed to provide distribution services for the quality controlled data in formats that meet user needs and to ensure that the original and quality controlled data are submitted to several world data center archives.

FISCAL YEAR 2004 PROGRESS

The data assembly center (DAC) has made significant progress on all aspects of the year 1 work plan. Some items are not complete due to the late arrival of year 1 funds at FSU. With partners at SIO, WHOI, and other U.S. and international contributors to the SAMOS initiative, we have developed a protocol for daily transfer of meteorological and near-surface ocean data directly from research vessels at sea to the DAC. Agreements have been reached on standards for data transfer and provision of essential metadata (e.g., instrument heights, units, averaging methods, etc.). Through a data pilot project, two WHOI vessels, the *Knorr* and *Atlantis*, have been transferring data to the DAC since mid-May 2005. The data received are automatically reformatted and quality controlled by the DAC using software developed over the past 6 months. In addition, a ship profile database has been developed to store all essential metadata for each vessel providing data to the DAC. The database also provides tracking and version control for all data received. The DAC has developed a web page describing the SAMOS initiative (http://samos.coaps.fsu.edu) which will host free and open access to the quality controlled data files (public access to files and documentation are still under development). The DAC continues to liaise with U.S. and international research vessel operators laying the groundwork to expand the number of vessels providing data to the DAC.

The 2005 pilot project is a partnership between SIO, WHOI, and the DAC to develop and implement a ship-to-shore data exchange protocol for U.S. research vessels. The protocol includes daily email transmission of all one-minute averaged SAMOS observations collected for the previous day by each vessel to the DAC. A prototype data exchange format is in place and data transmissions are underway from the *Knorr* and *Atlantis*. SIO and WHOI are implementing shipboard scripts to generate the data emails and also provide detailed metadata for each vessel. The DAC continues to develop the automated data ingestion system, common formatting, file tracking, and data quality control procedures. The data flow for the pilot project (Figure 1) is at a stage where preliminary files are available for distribution to the science community approximately 5 minutes after the original data are received by the DAC (typically just after 0000 UTC).

The DAC has been working throughout its first year to establish data and metadata specifications for future SAMOS observations. With input from both U.S. and international partners, a list of primary and secondary parameters has been developed to meet SAMOS science goals. A SAMOS metadata specification has also been completed along with draft metadata forms and instructions that will be provided to vessels interested in participating in SAMOS data exchange. These forms have undergone initial review by our pilot project partners. All metadata from participating vessels are stored in a SAMOS metadata database developed by the DAC. Database development is ongoing and initial testing has shown positive results during the 2005 data pilot project. The database plays a key role in augmenting SAMOS data files with important metadata and all information will soon be searchable and freely available to the user community. Additional components of the database will track the files from arrival to archival and will provide for data quality statistics. In addition, data accuracy and precision targets have been drafted and are under consideration by members of the SAMOS community.

During FY2004, the DAC has been actively promoting the SAMOS initiative at U.S. and international meetings. We have coordinated efforts by other SAMOS panelist to introduce the SAMOS initiative to the Scientific Committee on Antarctic Research, the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM), the Climate Variability and Predictability program (CLIVAR), and the Global Ocean Surface Underway Data (GOSUD) pilot project. Feedback from the scientific and technical community has been supportive and constructive as the DAC develops the data collection and distribution system for SAMOS observations.

The SAMOS DAC continues to act as the primary liaison with a wide range of U.S. and international partners. Within the U.S. the SAMOS community has developed contacts and collaboration between the research, operations, and marine data collection communities. Lines of communication have been opened with several ship operators and with the University - National Oceanographic Laboratory System Council. In addition, the SAMOS initiative welcomes ongoing collaboration with NOAA Office of Climate Observation (OCO) and the National Science Foundation (NSF), and hopes to improve contacts with the satellite and modeling communities.

On the international level, there has been collaboration between members of the SAMOS community and participants in the Voluntary Observing Ship Climate (VOSClim) program, the World Climate Research Program Working Group on Surface Fluxes (WGSF), and the Global Ocean Surface Underway Data (GOSUD) pilot project. VOSClim members have provided valuable experience with marine metadata to help draft the SAMOS metadata specification. The WGSF is anticipated to provide input into the planned marine handbook and SAMOS metadata specification. GOSUD is focused primarily on near ocean surface measurements, but also collects international marine meteorological data. A dialog is underway to initiate an exchange of data and quality evaluation expertise.

Finally, the SAMOS community believes it is very important to continue close collaboration with both U.S. and international moored buoy programs. Although the 2nd workshop panel recommends that the focus of the SAMOS initiative be on ships, there is clear overlap in scientific goals for the SAMOS and buoy communities. Continued collaboration is needed for sensor development, calibration, multi-platform comparisons, and integrating ship and buoy data into more useful products.

As part of SAMOS, the DAC is conducting preliminary R/V to moored buoy comparison studies. In late 2003, the *Ronald Brown* was operating in the Gulf of Mexico and this provided an opportunity to compare the meteorological data from the *Ronald Brown* to observations from the National Data Buoy Center (NDBC) Gulf moorings. The *Ronald Brown* IMET data were compared to NDBC Gulf of Mexico buoy data whenever the vessel was within 75 km of a buoy. *Ronald Brown* IMET 1-minute shipboard data was averaged in the same manner as the NDBC buoy data. All atmospheric data were height adjusted to 10 m but sea temperatures were not adjusted for depth. Plots were created for each buoy and variable as well as plots combining all of the ship and buoy data (e.g., Figure 2). The data were also plotted for additional distances between the vessel and buoy to evaluate the spatial variability of the data (not shown). Overall, the buoy comparisons suggest that applying scientific quality evaluation to the *Ronald Brown* data can improve the usefulness of the observations. The evaluation also revealed that some

fundamental changes in either instrument location or observing practices are needed to significantly improve the data quality, especially for the shipboard winds. The quality of the true winds on the *Ronald Brown* varies widely from cruise to cruise, and this problem is confirmed by the comparison to the NDBC buoys.

PUBLICATIONS:

Refereed

Smith, S. R., 2004a: Focusing on improving automated meteorological observations from ships. *EOS, Trans Amer. Geophys. Union*, 85, 319.

Technical reports

Smith, S. R., 2005: *Shipboard Automated Meteorological and Oceanographic System (SAMOS) Initiative*. Report for 3rd session of the JCOMM Ship Observation Team meeting, 7-12 March 2005, IFREMER, Brest, France, 7pp., in press.

Smith, S. R., 2004: *GSOP report on Ocean Observations: Surface Meteorology from Research Vessels*. CLIVAR Global Synthesis and Observation Panel Meeting, Boulder, 7pp., in press.

Rolph, J. J., and S. R. Smith, 2004: *Ron Brown IMET data quality control report: September – November 2003*. RVSMDC report 04-01, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 10 pp.

Rolph, J. J., and S. R. Smith, 2004: *Polarstern AWS data quality control report: May 2003 – June 2004*. RVSMDC report 04-02, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 24 pp.

Smith, S. R., 2004b: *Report from the 2nd Workshop on High Resolution Marine Meteorology*, COAPS Report 04-01, Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, Florida, 32306-2840, USA, 31 pp.

CONFERENCE PROCEEDINGS/PRESENTATIONS

Bourassa, M. A., and S. R. Smith, 2004: Applications for Fine Resolution Marine Observations. 2nd *High Resolution Marine Meteorology Workshop*, April, Silver Springs, MD.

Smith, S. R., S. D. Woodruff, and S. Worley, 2005: Marine climatology from research vessels. Abstracts from *2nd International Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II)*, Exeter, UK, accepted.

Smith, S. R., 2005: Progress of the shipboard automated meteorological and oceanographic system (SAMOS) initiative. Abstracts from *2nd International Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II)*, Exeter, UK, accepted.

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Smith, S. R., E. C. Kent, and S. K. Cook, 2005: Shipboard Automated Meteorological and Oceanographic System (SAMOS) Initiative. Abstracts from *3rd session of the JCOMM Ship Observation Team*, Brest, France, in press.

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EDUCATION AND OUTREACH ACTIVITIES

At present, the DAC is not involved in outreach activities. We do annually participate in the FSU Young Scholars Program (YSP), by sponsoring the research activities of 2 high school students. The YSP students spend six weeks on the FSU campus taking classes and conducting directed research. We have been involved in the YSP program since 1998.

The SAMOS initiative has a number of educational goals. The focus of the training activities lies in the production of a handbook (or guide) to best procedures and practices for meteorological measurements at sea. The handbook is aimed at the sea-going research community and ships' technical staff. Topics will include information on preferred sensor location, calibration, in-situ comparisons, documentation, metadata, bulk flux methodology, and measurement error. Plans are for a dynamic handbook which will be available on-line. The structure proposed will have "drill down" capacity, keeping the top level of the handbook fairly simple and allowing users to search for additional technical detail if desired. In the future, users will be able to download relevant computer code, specifications, and technical information whether on land or at sea (as broadband ship-to-shore communication technology develops). Future plans also include holding training workshops for marine technicians. The handbook development is being led by C. Fairall at the NOAA Environmental Technology Laboratory.

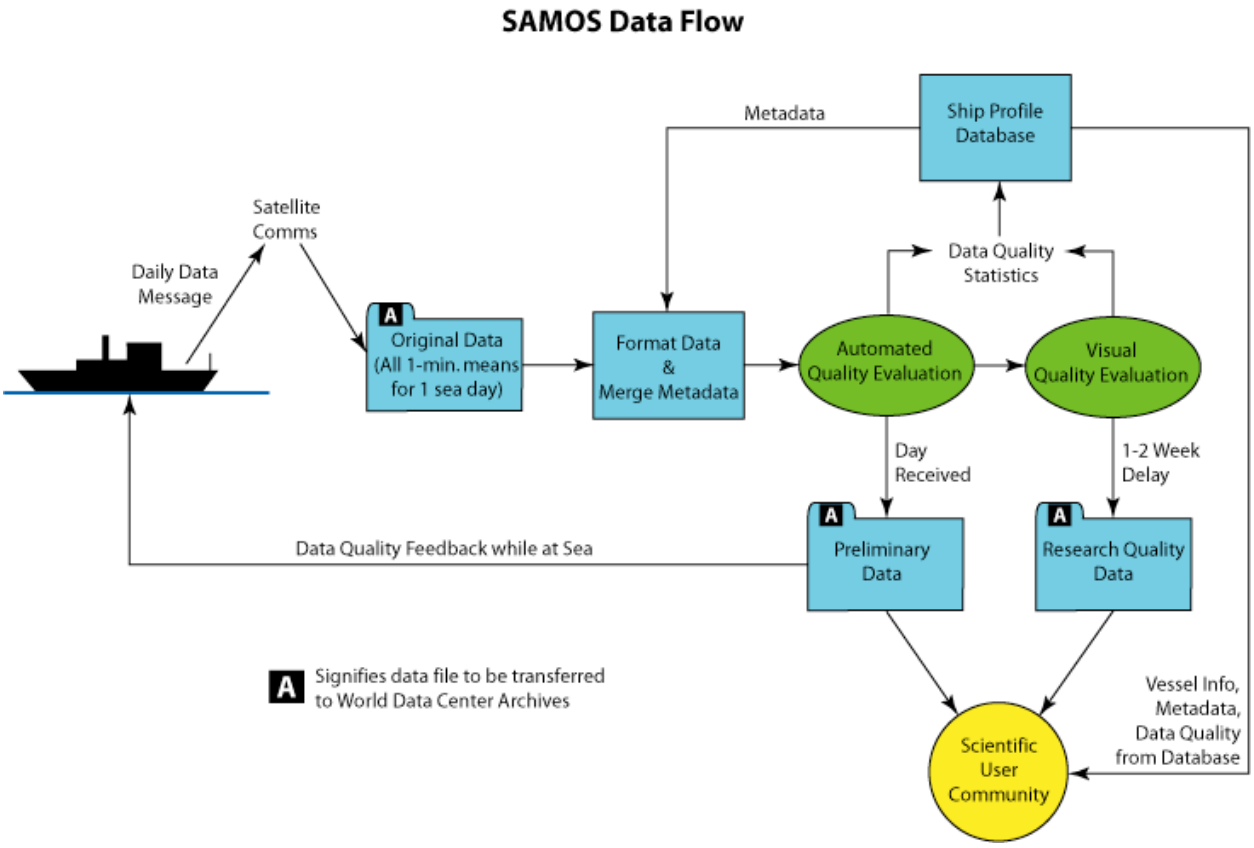

Fig. 1: SAMOS data flow to be tested during the 2005 pilot project with WHOI and SIO.

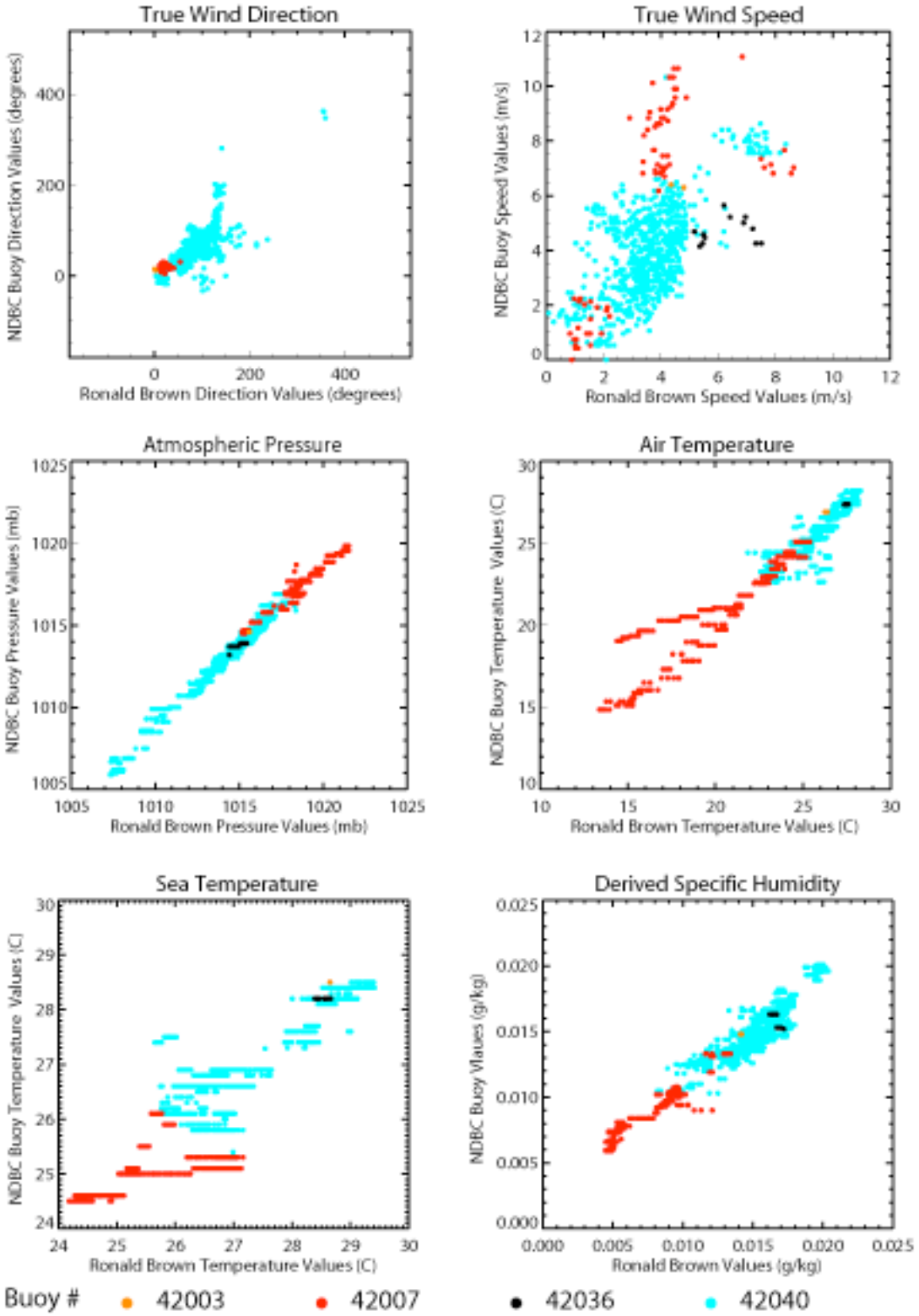

Fig. 2: Scatter plots of height adjusted meteorological data from the Ronald Brown versus four NDBC buoys. All values represent 10 minute averages (see text). The buoys are color coded according to the legend.

2005 NOAA Progress Report

Multi-sensor Improved Sea-Surface Temperature (MISST) for GODAE Task II

NOAA Grant - NA17J1223
05/01/2004-06/30/2005

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Related NOAA Strategic Plan Goal:

> Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

PROJECT BACKGROUND

One of the primary objectives of the MISST project is to produce an improved sea surface temperature (SST) analysis through the combination of observations from complementary infrared (IR) and microwave (MW) sensors. Multi-sensor blending requires parameterization of IR and MW retrieval differences, with consideration of diurnal warming and cool-skin effects.

This project has an objective to test and refine the cool skin and warm layer models with in–situ ocean temperature data from the Skin Depth Experimental Profiler (SkinDeEP). The improvements to the models will then be applied to the satellite-derived data thereby providing a superior SST product.

FISCAL YEAR 2004 PROGRESS

A detailed model for the temperature variations across the oceanic skin and near-surface layer was used to predict the value of the temperature difference from the forcing parameters for two datasets from SkinDeEP (Ward et al. 2004a). The model couples a parameterization for the skin-bulk temperature difference (Wick et al. 1996) with a complete one-dimensional, second-moment turbulence closure mixed-layer model (Kantha and Clayson 1994). The parameterization is used to estimate the temperature difference between the skin temperature (T_{skin}) ocean surface and the base of the skin layer ($T_{subskin}$), while the mixed-layer model predicts the temperature profile from the base of the skin layer to the depth of the buoy measurement (T_{depth}). A complete description of the coupled model and illustration of its ability to reproduce the temperature difference under different conditions is provided by Wick (1995). The model is very similar to that employed by Webster et al. (1996).

The SkinDeEP datasets used were from the Gulf of California in 1999 (War and Minnett 2005), and the Mediterranean in 2003 (Ward et al. 2004b). The conditions were generally similar: low wind and high insolation. Comparisons between the measurements and the modelled runs are currently being conducted to determine the model's capability to reproduce the measurements.

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PUBLICATIONS

Ward, B., and P.J. Minnett, Near–Surface Ocean Temperature, Journal of Geophysical Research,accepted, 2005 (funding acknowledged as National Oceanographic Partnership Program Award No. NNG04GM56G.)

2005 NOAA Progress Report

Implementation of One High Density XBT Line with TSG and IMET Instrumentation in the Tropical Atlantic

NOAA Cooperative Agreement No. NA17RJ1223
July 1, 2004 through June 30, 2005

Dr. Robert A. Weller
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Field Operations: Mr. Frank Bahr (fbahr@whoi.edu)
Engineering Support: Mr. David S. Hosom (dhosom@whoi.edu)
Physical Oceanography Department
Woods Hole Oceanographic Institution

Program Manager: Dr. Michael Johnson NOAA/OGP

Related NOAA Strategic Plan Goal:

Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

PROJECT SUMMARY

Central to present efforts to improve the predictability of climate is the need to understand the physics of how the atmosphere and ocean exchange heat, freshwater, and momentum and, in turn, to accurately represent that understanding in the models to be used to make predictions. At present, over much of the globe, our quantitative maps of these air-sea exchanges, derived either from ship reports, numerical model analyses or satellites, have errors that are large compared to the size of climatically significant signals. Observations made using the IMET technology on the Volunteer Observing Ships on long routes that span the ocean basins are essential to providing the accurate, in-situ observations needed to:

1) identify errors in existing climatological, model-based, and remotely-sensed surface meteorological and air-sea flux fields,
2) to provide the motivation for improvements to existing parameterizations and algorithms,
3) to provide the data needed to correct existing climatologies,
4) and to validate new model codes and remote sensing methods.

AutoIMET was developed by the Woods Hole Oceanographic Institution to meet the need for improved marine weather and climate forecasting. It is a wireless, climate quality, high time resolution system for making systematic upper ocean and atmospheric measurements. This interfaces to the NOAA SEAS 2000 (Shipboard Environmental (Data) Acquisition System) that automatically receives meteorological data (from the AutoIMET) and sends in automated one hour satellite reports via Inmarsat C. This system will document heat uptake, transport, and release by the ocean as well as the air-sea exchange of water and the ocean's overturning circulation.

Note that descriptions, technical information and data from the several VOS being serviced is posted on the site: http://uop.whoi.edu/vos/ Data (plots) are available for all ship sets.

Data (numbers) are available via anonymous ftp for the last data set only: ftp.whoi.edu/pub/users/fbahr/VOS. If data from previous times are desired please contact Frank Bahr at: fbahr@whoi.edu

There is a link to the site: http://frodo.whoi.edu where there is detailed information on the AutoIMET and ASIMET modules. Instrument design questions can be addressed to Dave Hosom at: dhosom@whoi.edu

Ship selection and interface to the NOAA SEAS system is via AOML. There is ongoing cooperation with Scripps via the CORCIII program as well as Southampton Oceanography Centre (SOC) of Southampton UK on Computer Flow Dynamics (CFD) for evaluation of the flow turbulence around the ship and its effect on the sensor placement. Some logistic support is provided by the Southern California Marine Institute on ship turnarounds. There is ongoing cooperation with the Atlantic Marine Ocean and Atmosphere Laboratory (AOML) in Miami on the Atlantic VOS program. There is also ongoing cooperation with many sensor manufacturers and the VOS people at the German Weather Service (Deutscher Wetter Dienst) in Hamburg Germany.

This project is managed in accordance with the Ten Climate Monitoring Principles.

FY 2004 PROGRESS

Ship selection for the Atlantic VOS was made late in 2003. AutoIMET systems were installed in June 2003 and December 2003 on the Pacific ships as part of a companion project.

SeaLand Express

January 2004. A survey of the SeaLand Express was carried out by Frank Bahr in Newport News, VA in preparation for the AutoIMET system installation.
March 2004. The AutoIMET system was installed on the SeaLand Express in Elizsabeth, NJ by Frank Bahr, Craig Marquette, Alan Gordon and Dave Hosom. The time in port was short and the weather was nasty. Steve Cook and Jim Farrington of NOAA helped with the AutoIMET installation and did the new NOAA SEAS 2000 installation on the bridge. The system was operating well with the exception of SST.

May 2004. Frank Bahr visited the ship in Elizabeth NJ to trouble shoot the SST system. The SST sensor (SeaBird 48) self records one minute data but was not being transmitted via the HullCom (acoustic modem) to the logger on the bow mast. The "Local" and "Remote" HullCom units were re-located to try to get a better acoustic path. The system was still not working properly. The SST and HullCom units were removed from the ship and returned to WHOI. The units were tested and WHOI and found to be operating properly, pointing to the acoustic path as the problem. It is possible to re-locate the "Remote" HullCom so that the

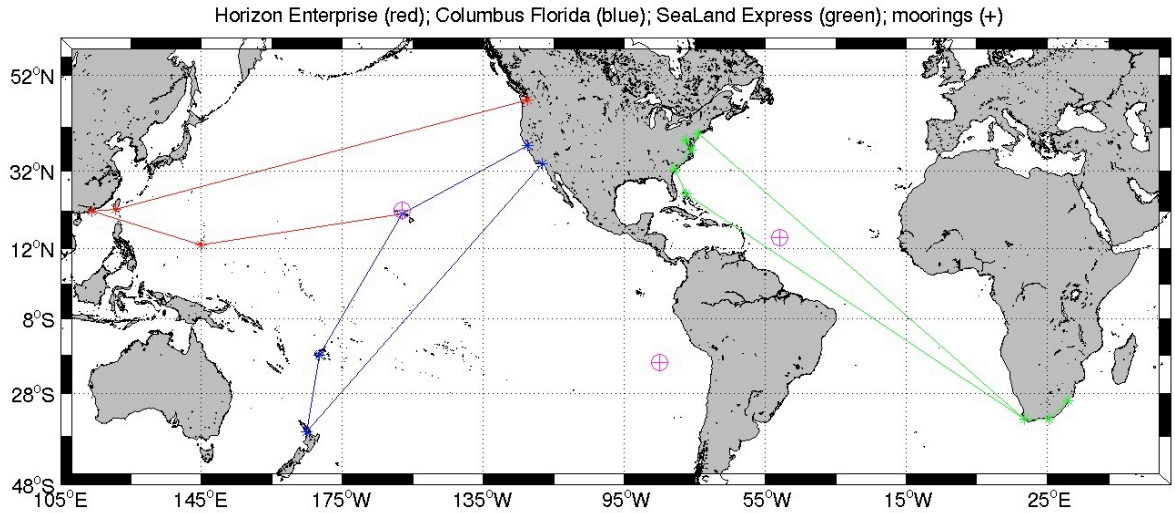
acoustic path is very short by using a 100 foot long cable between the "Remote" HullCom and the SBE48. This will be installed in June.

June 2004. Frank Bahr and Laura Hutto reinstalled the SST and HullCom units on the SeaLand Express in Elizabeth NJ. There are reports of high wind "spikes" in the data, therefore a new WND module will be taken to the ship as well as a new IMET GPS to monitor "real wind" in post processing. The "real wind" currently is calculated in the NOAA SEAS 2000 system using the SEAS GPS data.

August 2004. The wind sensor encoder failed and was replaced when the ship was in Baltimore, MD. Encoder failures seem to be due to overvoltage from the power supply coupled with ship power surges.

October 2004. The system was turned around in Baltimore MD. The data will be processed and be available on the web. The in port time was very short and the SST could not be serviced since there was welding in the hold that the SST is located in. A SST replacement is planned when the ship returns to Baltimore. The existing batteries should maintain SEAS data from the SST through December 2004 and the SST logger will continue until May 2005 even without battery changes.

ROUTE MAP



Note the Ocean Monitoring Stations (circle with cross) being operated by WHOI.

Conferences and meetings.

The Climate Observation Program Workshop in Silver spring, MD was attended by Dr. Robert Weller, Mr. Frank Bahr and Mr. Dave Hosom. The data conference was attended by Mr. Frank Bahr and Mr. Dave Hosom.

FY 2005 PLANS

Turnaround of the AutoIMET system will be carried out every six months.

The original stand-alone ASIMET modules will all have been converted to the new Auto-IMET systems and these will have been installed on the three active ships, Horizon Enterprise, Columbus Florida, and Sealand Express. A forth ship is scheduled to have a system installed in 2005 making a total of four VOS with Auto-IMET / NOAA SEAS systems that report via Inmarsat C in real time and store one minute data for retrieval every six months. This program is in an operational support mode for the current ships.

FY 2005 BUDGET

	(Received)	(Budgeted)
Funding Year	7/1/04	7/1/05
	6/30/05	6/30/06
	$158,000	$166,000

Any reduction in the funding will result in reduced labor and reduced scope of work.

NOAA-CICOR Progress Report

Air-Sea Interaction in the Eastern Tropical Pacific ITCZ/Cold Tongue Complex.

NOAA Grant Numbers: NA87RJ0445 and NA17RJ1223

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Program Manager: Mike Patterson, NOAA Office of Global Programs

Related NOAA Strategic Plan Goal: Goal 2- Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

PROJECT SUMMARY

As part of the NOAA funded Pan American Climate Study (PACS), two surface moorings were deployed on 125° W, one at 3° S (cold tongue) and one at 10° N near the northernmost climatological position of the Inter-Tropical Convergence Zone (ITCZ). Each surface buoy carried two complete sets of meteorological sensors (wind velocity, air and sea temperature, incoming shortwave radiation and incoming longwave radiation, humidity, barometric pressure, precipitation, surface currents), and the heat, mass; and momentum fluxes have been computed using state-of-the-art bulk formulae (Fairall et al., 1996). The mooring lines carried temperature, conductivity, and velocity sensors to observe upper ocean variability in the upper 200 m. The data from the northern mooring returned the first accurate and complete time series of the air-sea fluxes of heat, freshwater, and momentum in the eastern Pacific warm pool beneath the northernmost climatological position of the Inter-Tropical Convergence Zone (ITCZ). This data set is also unique because it spans the strong El Niño event of 1997-98 and the onset of the subsequent La Niña. Analysis of this data has had two principle foci: (1) Understanding of the balance of processes that set SST, and (2) Characterization of air-sea fluxes of heat, momentum, and freshwater in these two climactically and meteorologically important regions. Graduate student Tom Farrar, who started his Ph. D. thesis work in October 2004 under the supervision of Weller, will use the high quality PACS observations to study the role of air-sea exchange and upper ocean processes in setting SST in these two contrasting regions.

In order to address the goal of improving the simulation and prediction of sea surface temperature in the eastern tropical Pacific, a quantity known to be important to weather and climate over the Americas, Farrar and Weller have compared the high quality meteorological data from the buoy to surface fields commonly used to force ocean models (Farrar et al., 2004). The comparison focused on the reanalysis fields from the National Center for Environmental Prediction (NCEP1 and NCEP2; Kalnay et al., 1996; Kanamitsu et al., 2002) and on the operational model of the European Centre for Medium Range Weather Forecasting (ECMWF). The models do a fair job of representing many of the qualitative features of the observed heat and momentum fluxes, such as the ENSO signal. For example, all three flux products

qualitatively represent the observed increase in heat flux to the equatorial cold tongue (3 ºS) as the tropical Pacific transitioned from El Niño to La Niña around May 1998 (Figure 1). However, all of the models exhibit significant errors in the net heat flux to the ocean. The errors are comparable in size to the observed net heat flux. For example, at the 10 ºN site, the NCEP 2 monthly mean heat flux was of the wrong sign for 7 of 17 months, and the ECMWF product had the wrong sign for 9 of 17 months. There are other errors that could have significant effects on long term oceanic simulations. For example, the equatorial cold tongue at the 3 ºS site was especially strong during May-Sept 1998 due to La Niña. All three model flux products had time mean heat fluxes that were roughly 70 W/m^2 too low during this period. The observed depth of the main thermocline during that time averaged 43 m, so the heat flux errors are large enough to cause an error in simulated surface temperature of more than -4 ºC over the 5 month period. In addition to examining the accuracy of common forcing fields, Farrar and Weller have recently begun discussion with Marcus Jochum (NCAR) about using the mooring observations to examine the success of ocean models in representing physical processes important to simulation of SST on diurnal to seasonal timescales.

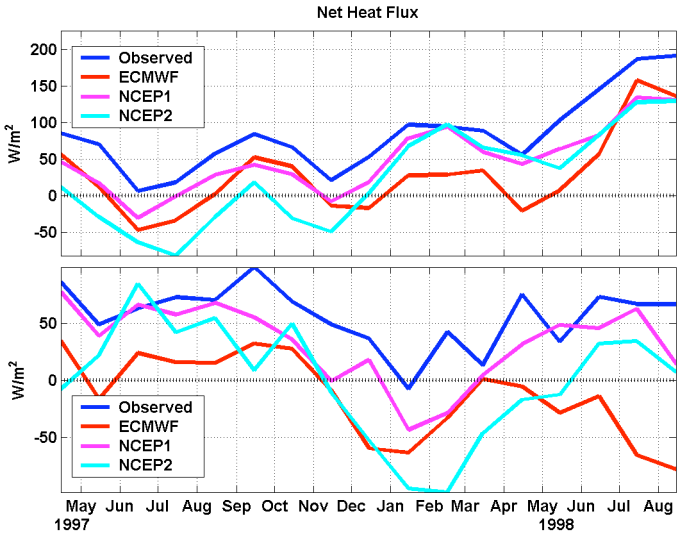

Figure 1. Monthly mean surface heat flux at the moorings and in three gridded products used to force ocean models. Upper panel: 3ºS, 125ºW site. Lower panel: 10ºN, 125ºW site.

The well-resolved time series of upper-ocean temperature and velocity, together with the accurate estimates of air-sea heat fluxes and satellite observations of SST, allow examination of the relative importance of surface heat fluxes and horizontal advection in setting the local SST. The residual of the temperature balance equation can be used to assess the role of vertical mixing and other unresolved processes. Analysis of the surface layer temperature balance has been carried out at both mooring sites, and results are being prepared for publication. At the southern site, horizontal advection was important throughout most of the mooring deployment. In particular, southward advection from the equatorial cold tongue was important in bringing about the local transition from El Niño to La Niña states. At the northern site, the surface temperature balance was primarily between surface heating and vertical mixing during the 1997

ITCZ season, but the balance shifted to one of surface heating and horizontal advection during the trade-wind season (Figure 2).

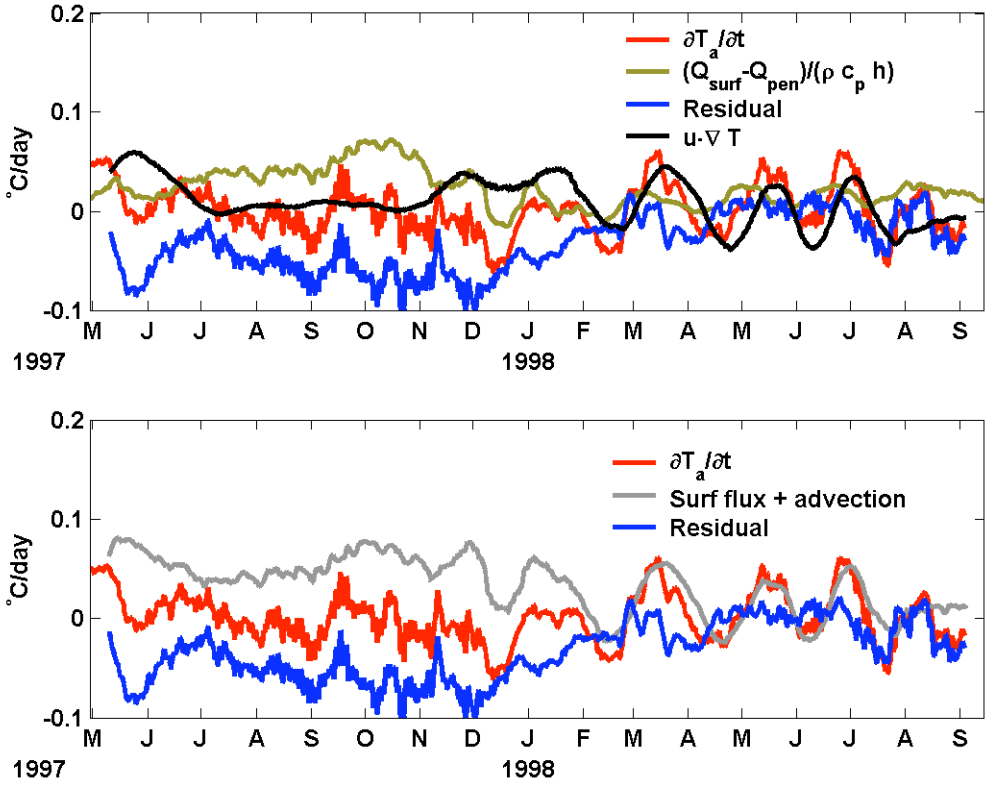

Figure 2. Terms in surface layer temperature balance at the 10ºN, 125ºW site. The terms estimated are: rate of change of layer-averaged temperature ($\partial T_a/\partial t$), heating of the layer associated with surface heat flux ($(Q_{surf}-Q_{pen})/(\rho c_p h)$), and horizontal advection ($u\cdot\nabla T$). In the lower panel, the surface heating term and horizontal advection term have been combined to more clearly show their contribution to rate of change of temperature.

Prominent meridional current fluctuations with a period of about 2 months (Figure 3) were observed in the mooring data at the northern site, and these current fluctuations exerted a strong influence on the local SST through horizontal advection (Figure 2), causing SST to fluctuate with about a 2 month period from January-June of 1998. The SST fluctuations associated with this signal were substantial, with peak-to-peak amplitudes ranging from 0.5-0.8ºC. The two month signal in meridional currents was linked to a previously recognized sea surface height signal that is strongest in the latitude band 9-13ºN east of 120ºW (Miller et al., 1985; Perigaud, 1990; Giese et al., 1994). To resolve discrepancies in prior studies of the signal (Perigaud, 1990; Giese et al., 1994), Farrar and Weller also worked to characterize the signal observed at the mooring within its larger spatial and temporal context using satellite SST and sea surface height measurements (Figure 4). The signal was found to be associated with relatively short (5-15º wavelength) baroclinic Rossby waves. Farrar and Weller also found evidence that the intraseasonal velocity variability and its annual cycle are associated with instability of the westward flowing North Equatorial Current as it intensifies in the spring of each year. The mooring observations were

instrumental in this study, because they allowed establishment and understanding of the link between the intraseasonal SSH and SST fluctuations. It is hoped that this improved understanding of mesoscale oceanic variability and its impact on SST in the region will allow for improved prediction of the oceanic mesocale SST field at monthly to seasonal timescales. This could be particularly important in the region of 9-13ºN in the eastern tropical Pacific, one of the world's most prolific regions of tropical cyclogenesis.

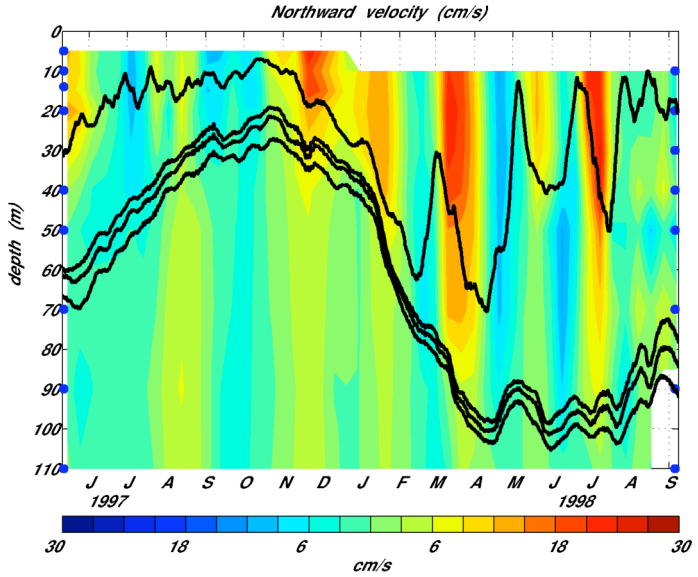

Figure 3. Meridional velocity observed at 10º, 125ºW (10 day averages). The upper black line marks the mixed layer depth, and the lower three black lines mark isotherms in the thermocline (19, 22, and 24º C). The blue circles on the left and right edges of the figure indicate current meter depths.

Continuing progress will allow for the completion of the analysis of the data collected at 125°W during 1997-1998 in conjunction with preparation of a Ph. D. Thesis. The effort has shifted to examination of the surface forcing, upper ocean dynamics, and evolution of the thermal structure at 3°S. With that complete, we will use remote sensing and TAO data in conjunction with the upper ocean observations and air-sea fluxes from the two mooring sites to extend the effort to identify the important physical processes that drive the evolution of SST and upper ocean thermal structure over the broader region spanning the equatorial cold tongue and in the eastern Pacific warm pool.

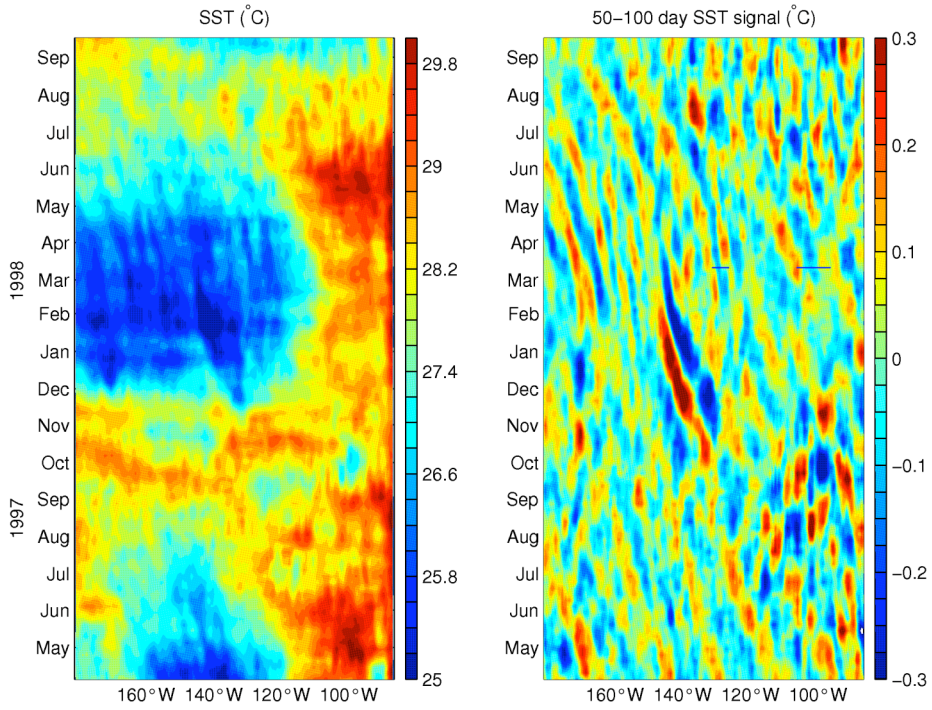

Figure 4. Left panel: Longitude-time plot of SST along 10ºN. Right panel: SST filtered to pass variability in the 50-100 day period, 2-15º zonal wavelength band. The westward propagation of the SST signals is caused by advection associated with Rossby waves.

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2005 NOAA Progress Report

Ocean Reference Stations

NOAA Cooperative Agreement No. NA17RJ1223 (subpoints 28, 29, and 59)
July 1, 2004 through June 30, 2005

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Related NOAA Strategic Plan Goal:

Goal 2 - Understand Climate Variability and Change to Enhance Society's Ability to Plan and Respond

OVERVIEW

The goal of these related observational projects is to maintain long-term surface moorings, known as Ocean Reference Stations, as part of the integrated ocean observing system. These Ocean Reference Stations collect long time series of accurate observations of surface meteorology and upper ocean variability in regions of key interest to climate studies. The resulting meteorological and oceanographic observations provide a set of high quality air-sea fluxes of heat, freshwater and momentum. The scientific rationale for the collection of these flux products is manifold: 1) to describe the upper ocean variability and the local response to atmospheric forcing; 2) to motivate and guide improvement to atmospheric, oceanic, and coupled models; 3) to calibrate and guide improvement to remote sensing products and capabilities; and 4) to provide anchor points for the development of new, basin scale fields of the air-sea fluxes. Model, satellite, and climatological fields of surface meteorology and air-sea fluxes have large errors; high quality, in-situ time series are the essential data needed to improve our understanding of atmosphere-ocean coupling and to build more accurate global fields of air-sea fluxes.

Under this effort three sites will be maintained: the site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS) at 15°N, 51°W, and a site north of Hawaii near the Hawaii Ocean Timeseries (HOT) site. The Stratus and NTAS sites had surface moorings which were deployed and serviced annually under NOAA OGP support; these sites have now transitioned to long-term Ocean Reference Stations. The Hawaii site is a new Ocean Reference Station, in collaboration with investigators that have made shipboard and moored observations in that region in recent years. In the management of the **Ocean Reference Stations** project, four tasks have been identified. First, there is the engineering, oversight, and data management (**Task I**); work in this area is underway and progress reported below. Second, the maintenance of the Stratus site (**Task II**), also with work underway and progress reported below. Third, the maintenance of the NTAS site (**Task III**) which in FY2005 shifted to support as one of the operational Ocean Reference Stations. Fourth, the establishment of the Ocean Reference Station at Hawaii (**Task IV)**, whose first year

of operation was successfully completed. Progress on each of the Tasks is reported in more detail below.

PROGRESS

Task I: Engineering, oversight and data:

Construction of the new buoy for use at the Ocean Reference Stations was completed. All three sites are now occupied by the modern design (Fig. I-1). These new buoys replaced the 15 to 20 year old hulls previously used, which were degrading (corrosion of the welded aluminum) and were expensive to ship as they do not fit inside a sea container like the new hulls.

Figure I-1: The old rigid hull (left) and the new modular buoy (right). Photo taken during the December 2004 Stratus deployment and recovery cruise.

Data processing continues on schedule. New routines have been developed to provide consistent processing over the multi-year deployment. The "best" quality meteorological and flux data is being made accessible through the web, within a year of recovery. The post-doctoral investigator (Keir Colbo: supported under sub-point 08) working on the Stratus data set has also submitted a paper outlining the expected accuracy of the meteorological and flux data products.

The oversight task coordinates the common data tasks for the three sites. Oceanographic (velocity, temperature, salinity) and surface meteorological data (wind speed and direction, air and sea surface temperature, rain, incoming shortwave and longwave, relative humidity, and barometric pressure) are processed and stored on disks attached to our workstations. Hourly meteorological data are transmitted via Argos telemetry and made available via an FTP server and a website with download capability. We maintain a public access archive of Upper Ocean Processes Group data from mooring deployments.

As we look ahead to adding new sensors to the meteorological suite and/or telemetering subsurface data, using Argos becomes increasingly untenable due to data rate limitations. More importantly, we have found that the Argos transmissions introduce noise in some sensors and can degrade data quality. Preliminary trials with an Iridium modem on the Hawaii buoy indicate that meteorological data can be successfully packaged by the controller, sent via Iridium short-burst messaging and received on shore as an email attachment. With Add-Task funding for FY 200x we are pursuing development of an Iridium telemetry subsystem and implementation of an automated, shore-based decoding and processing system for the telemetered data.

Task II: Stratus Site:

The stratus surface mooring was originally deployed under a previous grant (from the Pan American Climate Studies) in October 2000. It has been annually redeployed and recovered

since that time. During the deployments, hourly-averaged surface meteorology was available from the buoy in near real time via Service ARGOS and a WHOI ftp site. Data exchanges were made with ECMWF, NCEP and others to examine numerical weather prediction model performance and examine air-sea fluxes under the stratus clouds. The telemetered meteorological data are also available via the website maintained for this site (http://uop.whoi.edu/stratus). Internally recorded 1-minute meteorological data as well as the oceanographic data, which are only internally recorded, were downloaded from the recovered instrumentation. Data recovery was good, post-calibrations are being done, and data files have been shared with colleagues. Preliminary cruise reports are filed with the State Department soon after the cruise; final documentation that goes to foreign observers and the State Department includes copies of the underway data and a final cruise report (Colbo et al., 2005). Telemetry from the buoy presently deployed indicates that it is on station and both meteorological systems are functioning well.

Work this year included deploying the new and recovering the old mooring, doing calibrations (both pre and post-deployment), data processing, writing cruise reports, preparing mooring hardware and instrumentation for the new deployment and cleaning and assessing the recovered equipment. The FY2005 deployment was carried out aboard the *R/V Ronald H. Brown* which sailed from Arica, Chile on December 5, 2004 and arrived into Valparaiso, Chile on December 24, 2004.

The planning and observational preparation for the cruise begins many months before the deployment. During the spring of 2004 instruments were gathered and placed on the new mooring buoy for testing. This testing of the instrumentation while mounted on the buoy, and exposed outdoors, is important for the proper gauging of accuracy and reliability. This on-going burn-in period typically lasts three or more months. In September of 2004, members of the UOP group loaded the *R/V Ron Brown* in Charleston, with some additional loading a month later in Miami.

The Stratus 4 mooring was recovered on December 11th with no undue problems. The old mooring is traditionally recovered first so as to assess any problems that may have arisen, and to hence make last minute changes on the new mooring. Unlike the previous year where certain upper ocean instruments were fouled by fishing line, no obvious damage to the mooring instrumentation was visible. Biofouling was also reduced this year, whether as a result of new antifoulant paints or ocean conditions is unclear. The Stratus 5 mooring was deployed on December 13th.

On the buoy we measure air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line the instrumentation is concentrated in the upper 300m and measures temperature, salinity, and velocity. During the deployment, high data rate (up to 1 sample per minute) data are stored in each instrument. The internally recorded data goes through processing, has calibration information applied, and is subject to preliminary analyses before being made publicly available on our website. In the interim, preliminary versions are made available upon request.

Hourly surface meteorological data are archived at WHOI, arriving within hours of when it was observed. These data are exchanged in near real time with ECMWF and NCEP; they in turn

provide operational data at the grid point nearest the model. It is also shared with the Chilean Navy (SHOA). The same data are shared with CLIVAR investigators, especially modelers interested in the Stratus region, with VAMOS investigators in the U.S. and in South America. It is also sent to Peter Glecker at PCMDI for use in the SURFA project. This meteorological data are used to assess the realism of operational atmospheric models in the stratus region. Once per minute as well as hourly surface meteorological time series are provided to the EPIC and VEPIC investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin) after recovery. The surface meteorological data have been made available to the satellite community (including radiation – Langley, winds – Remote Sensing Systems and JPL, SST – Dick Reynolds, all variables – the SEAFLUX project). The oceanographic data are being used by Weller and a Postdoctoral Investigator (Keir Colbo) at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. In parallel it will be compared with ocean models results (with Ragu Murtugudde, Univ. of Maryland and Markus Jochum, NCAR). The initial archive is maintained by the Upper Ocean Processes Group at WHOI, which runs a public access server for their mooring data. We are working with the International Time Series Science Team to develop a number of sites that will maintain as many records of time series stations as can be collected to facilitate access to such data.

Both before the recovery of the old buoy and after the deployment of the new buoy, *in situ* comparisons of the ship's and buoys' twin meteorological sensors were carried out. These comparisons have been a crucial component of the post-recovery data processing, particularly for sensitive instruments which may suffer damage during the return shipment to WHOI. Extensive shipboard meteorological and air-sea flux instrumentation was installed on the *Ron Brown* and operated by Chris Fairall and Dan Wolfe from the NOAA Environmental Technology Laboratory in Boulder, CO. The air-sea flux system consists of a fast turbulence system with ship motion corrections, a mean T/RH sensor, solar and IR radiometers, a near surface sea surface temperature sensor, a Particle Measurement Systems (PMS) Lasair-II aerosol spectrometer, and an optical rain gauge.

ETL also operated three remote systems: a Vaisala CT-25K cloud base ceilometer, a 35 GHz vertically pointed Doppler cloud radar, and a 20.6 - 31.65 GHz microwave radiometer. ETL has an integrated system in a seatainer that includes a Doppler Ka-band cloud radar (MMCR) and a microwave radiometer. The system can be used to deduce profiles of cloud droplet size, number concentration, liquid water concentration etc. in stratus clouds. If drizzle (i.e., droplets of radius greater than about 50 μm) is present in significant amounts, then the microphysical properties of the drizzle can be obtained from the first three moments of the Doppler spectrum. The radar is extremely sensitive and can detect most tropical cirrus and fair weather cumulus clouds. The Doppler capability can also be used to measure in-cloud vertical velocity statistics.

Marine aerosol concentrations and the processes that produce and remove the aerosols in the southeast Pacific have rarely been studied. Building on last year's results, the Texas A&M University (TAMU) Aerosol Research Group returned to the ship with two instruments to study a large spectrum of aerosol diameters from 12-nm to 15-mm. A Tandem Differential Mobility Analyzer (TDMA) investigated aerosols diameters up to 800-nm, while an Aerodynamic Particle Sizer (APS) model 3321 produced by TSI looked at the remaining aerosols up to 15-mm. The data collected will allow for a better understanding of the marine aerosol's chemical composition and distribution in this region of the world.

The Stratus cruises serve the wider scientific community by providing a platform on which to study the regional ocean. Additional researchers who participated in collaborative research or benefited from shared ship time in FY2005 have come from many institutions: NOAA Environmental Technology Laboratory, Servicio Hydrografico y Oceanografico de la Armada (Chile), University of Concepcion (Chile), Texas A&M University, University of Chile, CSIRO (Australia), and University of Miami.

These collaborations have included: enhanced regional surface flux and lower atmosphere surveys, both offshore and within Chilean coastal waters (NOAA ETL, CSIRO, U. Miami, U. Chile), extensive hydrographic surveys with CTDs and XBTs (multi-user), water sampling in support of biological monitoring (U. Concepcion), regional aerosol surveys of the atmospheric boundary layer (Texas A&M), and the deployment of a tsunami warming buoy (Chilean Navy).

The December 2004 stratus cruise also hosted a teacher from NOAA's Teachers-at-Sea program (Mary Cooke), as well as NOAA program managers and educational staff. During the cruise, the teacher assisted with science operations including mooring deployments and recoveries. She also hosted web broadcasts, wrote daily logs, took photos, and interviewed science members and crew. This information was used to communicate with her classroom, as well as those of other land-based teachers. All of the video, pictures, and logs are available at http://www.ogp.noaa.gov/stratus/. The cruise also served as the germination point for the first NOAA Teacher-at-sea book, describing Mary Cook's experiences on the cruise (http://www.noaanews.noaa.gov/stories2005/s2417.htm). Additionally, the ship has played host to visiting delegations of local officials and school children during its port calls.

To further support ground-truthing of satellite data and increased understanding of the ocean in the eastern South Pacific, 15 drogue surface drifters and 8 profiling ARGO floats were deployed in the South Pacific along the cruise track.

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SEMINARS AND PRESENTATIONS:

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"The variability under the stratus deck - surface mooring results", VAMOS Panel Meeting 7, Guayaquil, Ecuador, Feb 2004

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"How Accurate are Surface Meteorology Measurements from a Buoy?", *First International CLIVAR Science Conf.*, 21-25 June 2004, Baltimore, MD (poster).

Task III: NTAS Site:

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction on seasonal to decadal time scales. The strategy is to maintain a meteorological measurement station at approximately 15° N, 51° W through successive (annual) turn-arounds of a surface mooring. Redundant meteorological systems measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

NTAS has two primary science objectives: 1) Determine the air-sea fluxes of heat, moisture and momentum in the northwest tropical Atlantic using high-quality, in-situ meteorological measurements from a moored buoy. 2) Compare the in-situ fluxes to those available from operational models and satellites, identify the flux components with the largest discrepancies, and investigate the reasons for the discrepancies. An ancillary objective is to compute the local (one-dimensional) oceanic budgets of heat and momentum and determine the degree to which these budgets are locally balanced.

A mooring turn-around cruise was conducted on the NOAA ship *Ronald H. Brown* in order to retrieve the existing mooring (NTAS-4, deployed 21 February 2004) and replace it with a new mooring (NTAS-5). In preparation for this cruise, three Air-Sea Interaction Meteorology (ASIMET) systems were assembled and tested. Two systems, comprised of the best performing sensors, were mounted on the newly developed 2.7 m modular ORS buoy in preparation for deployment. The NTAS-5 mooring was deployed on 11 March 2005 and the NTAS-4 mooring was recovered on 13 March. The period between deployment and recovery was dedicated to a comparison of the two buoy systems, with the shipboard system as an independent benchmark.

To ensure high-quality meteorological data, all NTAS-5 sensors were calibrated prior to deployment, and NTAS-4 sensors will be post-calibrated. A cruise report is in preparation.

Preliminary processing of the NTAS-4 meteorological data has been completed. Data return was excellent, with all sensors operating for the complete deployment period. The comparison period showed very encouraging results, indicating little degradation of NTAS-4 sensor performance after one year at sea. After post-calibration of the sensors, the corrected, 1-min data will be used for further analyses. The uncorrected, hourly Argos data from NTAS-4 are available on-line from the Upper Ocean Processes (UOP) group web site (http://uop.whoi.edu/projects/NTAS). At present, about 6 months of hourly meteorological data from NTAS-5 are also available for examination on the UOP web site. Preliminary evaluation indicates that all NTAS-5 sensors are performing as expected.

Meteorological sensors from NTAS-1, 2 and 3 have been post-calibrated, and NTAS-1 and 2 data have been post-processed. Hourly averaged files from the resulting data sets have been posted on the UOP web page. The 1 min data are being used as the basis for air-sea flux computations using bulk formulas.

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Task IV: Hawaii Site:

The Hawaii Ocean Time-series (HOT) site, 100 km north of Oahu, Hawaii, has been occupied since 1988 as a part of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS). Among the HOT science goals are to document and understand seasonal and interannual variability of water masses, relate water mass variations to gyre fluctuations, and develop a climatology of high-frequency physical variability in the context of interdisciplinary time series studies. The primary intent of the WHOI Hawaii Ocean Timeseries Station (WHOTS) mooring is to provide long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and contribute to the goals of observing heat, fresh water and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. It is expected that establishment of the WHOTS mooring will accelerate progress toward understanding multidisciplinary science at the site, provide an anchor site for developing air-sea flux fields in the Pacific, and provide a new regime in which to examine atmospheric, oceanic, and coupled model performance as well as the performance of remote sensing methods.

The first ORS mooring was deployed at the HOT site in August 2004, representing a two year advancement of the timetable originally proposed (financial support for this acceleration was provided by the NOAA Office of Climate Observations as an Add Task). The observational strategy is to maintain a surface mooring at approximately 22.75° N, 158° W, instrumented to obtain meteorological and upper ocean measurements, through successive (annual) turnarounds done in cooperation with HOT investigators. Redundant meteorological systems on the surface buoy measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas. Subsurface oceanographic sensors on the mooring are being provided through cooperation with Roger Lukas (U. Hawaii; funded by the National Science Foundation). The WHOTS mooring is nearby the Multi-disciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN) mooring of Tommy Dickey (U.C. Santa Barbara; funded by the National Oceanographic Partnership Program). We have established links with U. Hawaii and the MOSEAN group to improve the efficiency of field logistics.

A mooring turn-around cruise was conducted in 2005 on the Scripps ship *Melville* in order to retrieve the existing mooring (WHOTS-1, deployed August 2004) and replace it with the new mooring (WHOTS-2). In preparation for this cruise, three Air-Sea Interaction Meteorology (ASIMET) systems were assembled and tested. Two systems, comprised of the best performing sensors, were mounted on a 2.7 m modular ORS buoy in preparation for deployment. The WHOTS-1 mooring was recovered on 26 July 2005 and the WHOTS-2 mooring was deployed on 28 July. Periods of about 24 hours prior to the WHOTS-1 recovery and after the WHOTS-2 deployment were dedicated to an intercomparison of the buoy and shipboard meteorological systems. The WHOTS-2 mooring was used as a test-bed for implementation of an Iridium data telemetry system, developed under the ORS Engineering, Oversight and Data project. Initial results indicate that the system is working, providing a data stream that is redundant with the standard Argos telemetry. To ensure high-quality meteorological data, all WHOTS-2 sensors were calibrated prior to deployment, and WHOTS-1 sensors will be post-calibrated. A cruise report is in preparation.

Preliminary processing of the WHOTS-1 meteorological data has been completed. Data return

was very good, with all sensors operating for the complete deployment period except one wind sensor which failed after about 5 months. The intercomparison period showed encouraging results, but did indicate that some sensor positions on the 2.7 m buoy tower may be suboptimal. After post-calibration of the sensors, the corrected, 1-min data will be used for further analyses. The uncorrected, hourly Argos data from WHOTS-1, and the first few weeks of data from WHOTS-2, are available on-line from the Upper Ocean Processes (UOP) group web site (http://uop.whoi.edu/projects/WHOTS).

2005 NOAA/CICOR Progress Report

Long-Term Evolution and Coupling of the Boundary Layers in the STRATUS Deck Regions of the Eastern Pacific

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 08
July 1, 2004 through June 30, 2005

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Program Manager: Dr. Michael Patterson NOAA/OGP

Related NOAA Strategic Plan Goal:

Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

PROJECT SUMMARY

The stratus project has been successful in elucidating the physical processes that maintain the observed cool surface waters of the Peru-Chile stratus region. Colbo and Weller (2005a) synthesized the mooring data with historical hydrographic and satellite data to show that the upper ocean heat and salt budgets had a large component that was contributed by the divergence of the "eddy" flux. This large transport of cool, fresh water from the coastal upwelling region to the deep ocean through the eddy field has not been noted before. It also helps explain the deficiencies observed in many global models of the region, which are not eddy resolving, and hence cannot adequately capture this important oceanic transport.

In using the ocean reference station data for this project, as well as others, it was necessary to understand the accuracy of the basic surface meteorology and the derived flux products. To this end a series of meetings was organized for the scientific and engineering staff at WHOI with direct experience of the IMET package. (The IMET package is the standard meteorological sensor suite used on all the Ocean Reference Stations, as well as most US Volunteer Observing Ships and Research Vessels.) These meetings have been synthesized into a single document which has now been transformed into a journal article (Colbo and Weller 2005b). It lays out the expected accuracy of all the individual meteorological sensors in detail, and shows how those errors propagate into the heat, freshwater and momentum fluxes. This is a crucial step in validating the observations and is necessary for any future climate studies involving the Ocean Reference Station data.

The first four years of surface meteorological and air-sea flux data is being used to describe and characterize the surface forcing and atmosphere-ocean coupling observed under the stratus cloud deck at a site close to the region of climatological maximum low cloud cover (Weller and Colbo 2005). This site is data sparse, and these buoy data provide the first accurate long time series that can be used to characterize the site. Both model and climatological values are found to differ significantly from the observations. Though the regime is basically a trade wind regime, with very stable wind direction, wind speed at times drops to low enough values to allow strong

diurnal warming in sea surface temperature. Strong diurnal variability is also found in other variables, including the incoming longwave radiation. Links between local variability at diurnal and synoptic time scales to regional synoptic variability are being explored. At the same time significant interannual variability and work is underway to examine whether or not this is tied change in the South Pacific subtropical circulation in the atmosphere and to other causes.

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Weller, R. A. and K. Colbo 2005: Surface Meteorology and Air-Sea Fluxes Under the Stratus Clouds off Northern Chile. In preparation.

CONFERENCE SEMINARS AND PRESENTATIONS (K. COLBO):

"What Maintains the Cold Ocean off of Peru": VOCALS Science and Implementation Workshop, Corvallis, 2004 (talk)
"Climate Observations from the Peru-Chile Stratus Deck": International CLIVAR Science Conference, Baltimore, 2004 (poster)
"How Accurate are Surface Meteorology Measurements from a Buoy?": International CLIVAR Science Conference, Baltimore, 2004 (poster)
"Observations from the subtropical Pacific Ocean: What sets SST under the clouds?": AGU Ocean Sciences, Portland, 2004 (poster)
"Moored Observations from Under the Stratus Deck": EPIC-PACS meeting, Boulder, 2003 (poster)

RECENT INDIVIDUAL SEMINARS (K. COLBO)

"Upper Ocean variability in the Chile-Peru Stratus"
University of New South Wales @ Australian Defense Force Academy --- March 2005
Woods Hole Oceanographic Institution --- April 2005
"What maintains the cool SST under the Chile-Peru Stratus Deck"
Oregon State University,
University of Washington,
University of British Columbia,
University of Victoria,
Institute of Ocean Sciences --- October 2004

INTERACTIONS WITH NOAA

Attend and present at the NOAA sponsored EPIC/PACS meeting, Boulder 2003
Attend and present at the NOAA sponsored VOCALS Planning Meeting, Corvallis, 2004
Discussions with NOAA scientists outside of NOAA sponsored meetings, including: Meghan Cronin, Mike McPhaden, Gregory Johnson, and Chris Fairall.

2005 NOAA/CICOR Progress Report

GLOBEC Data Synthesis

NOAA Cooperative Agreement No. NA17RJ1223 sub-point 23
July 1, 2004 through June 30, 2005

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Related NOAA Strategic Plan Goals:

Goal 1. Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.

Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

PROJECT BACKGROUND:

This project supports the US GLOBEC Georges Bank Phase IV yearly workshops and the symposia. These funds are used to defray the costs of the meeting facilities and pay partial or full travel support for those investigators whose presence at one or more of these meetings is deemed important by the US GLOBEC Georges Bank Executive Committee and yet may not have sufficient funds to attend the meetings on their own. The funds are also used to assist in the documentation of the symposia through the preparation of reports, which will be published both in hard copy and on the Program's web site (http://globec.whoi.edu/), as has been done in the past. During the fourth year of the project, funds will be used to assist in the planning and development of the book showing the results of the analysis and synthesis of the US GLOBEC George Bank program data sets and modeling efforts.

There are five US GLOBEC Georges Bank research projects in the Phase IV program. These are as follows:

The Physical Oceanography of Georges Bank and Its Impact on Biology
Robert Beardsley (WHOI), Ken Brink (WHOI), Dick Limeburner (WHOI), Jim Churchill (WHOI), Jim Ledwell (WHOI), Changsheng Chen (UMassD), James J. Bisagni (UMassD), Charles Flagg (BNL), Peter Smith (BIO), Ron Schlitz (NEFSC), Jim Lerczak (WHOI)

Zooplankton Population Dynamics on Georges Bank: Model and Data Synthesis

Peter Franks (SIO), James Pringle (UNH), Changsheng Chen (UMassD), Ted Durbin (URI), Wendy Gentleman (UW)

Patterns of Energy Flow and Utilization on Georges Bank
Dian Gifford (URI), James J. Bisagni (UMassD), J.S. Collie (URI), E.G. Durbin (URI), Michael Fogarty (NEFSC), Jason Link (NMFS), Larry Madin (WHOI), David Mountain (NMFS), Debbie Palka (NMFS), Michael E. Sieracki (BLOS), John Steele (WHOI), B.K. Sullivan (URI)

Tidal Front Mixing and Exchange on Georges Bank: Controls on the Production of Phytoplankton, Zooplankton and Larval Fishes
Robert W. Houghton (LDEO), Dave Townsend (UME), Changsheng Chen (UMassD), R. Gregory Lough (NEFSC), Lew Incze (BLOS), Jeff Runge (UNH)

Integration and Synthesis of Georges Bank Broad-Scale Survey Results
Peter Wiebe (WHOI), Carin Ashjian (WHOI), Larry Madin (WHOI), Dennis McGillicuddy (WHOI), Dave Mountain (NMFS), J.R. Green (NMFS), Peter Berrien (NMFS), S.M. Bollens (SFSU), Dave Townsend (UMaine), Ted Durbin (URI), Bob Campbell (URI), Barbara Sullivan (URI), Ann Bucklin (UNH), Jeff Runge (UNH).

FISCAL YEAR 2004 PROGRESS:
The scientific investigators in the projects listed above participated in a number of workshops or working group meetings during the year, some of which were supported by this project.

A special GLOBEC session was held at the AGU Ocean Science Meeting 26-30 January 2004 entitled "Understanding the physical and biological coupling of marine population dynamics". This special GLOBEC session was designed to provide a forum for the exchange of information resulting from multidisciplinary programs in the Northwest Atlantic, Northeast Pacific, and Southern Ocean and to provide a means for synthesis and integration across and within the programs. Of particular interest were modeling and observational studies that integrated biological and physical processes and provide a basis for future inter-comparisons between the regions. Especially encouraged were papers that considered: 1) linkages between regional physical and biological phenomena at seasonal to decadal time scales; 2) topographic control on mesoscale structure and its influence on population dynamics; 3) observations of physical processes which influence the physical and biological environments (e.g., cross-frontal exchanges, turbulent mixing); 4) retention mechanisms and life-history strategies other than passive use of mesoscale circulation features; 5) predator-prey interactions, including top predator effects; and 6) sources of mortality in early life stages.

Another special GLOBEC session will be held at the AGU Ocean Science Meeting, which will take place from 20 to 24 February 2006 in Honolulu, Hawaii.

The Third US GLOBEC Northwest Atlantic/Georges Bank Phase IV Science Meeting was held from 21 to 25 June 2004 at the Salve Regina University's Conference facility in Newport, Rhode Island. The primary goal of the meeting was to bring together the US GLOBEC Georges Bank Phase IV-funded and other science investigators to review the current research progress and continue efforts to synthesize and analyze the results to date. The program, which completed its field work in December 1999, began the synthesis phase in the summer of 2002 with five projects funded by NSF and NOAA. A listing of the projects is at:

http://globec.whoi.edu/globec-dir/phase4doc/project-titles.html with links to project summaries. This third in a series of meetings of the scientific investigators was held to promote the exchange of information and foster integration of results. Salve Regina University provided excellent conference facilities, including internet connections, onsite living accommodations, and other services. The meeting goals were:

* to enable scientific investigators to share results of the second year of synthesis work.
* to provide a forum for the integration and synthesis of findings among the groups.
* to plan for a third special collection of papers in Deep-Sea Research-II.

The DSR-II volume is now well underway.

The US GLOBEC Georges Bank target species meeting took place from 19 to 21 January 2005 in Durham, NH. The purpose of the meeting was to identify research areas where GLOBEC results suggest a new conceptual model of biological processes in the Georges Bank/Gulf of Maine region and to develop a plan for testing these hypotheses. Specific goals were to provide updates on population dynamics modeling, spatial distributions and of egg production, growth and mortality data; to identify important events or problem areas that need attention; to identify what data must be shared among groups to further the understanding of the target species; and to compare patterns of variability in target species with one another and with other important species. A meeting report containing additional detail about the meeting is available at: http://globec.whoi.edu/globec-dir/reports/data_workshops/targetspecies/report.shtml
A follow-up meeting is planned for fall 2005.

A U.S. GLOBEC Georges Bank Open Meeting was held in Woods Hole, MA on 19 and 20 April 2005 to discuss the Phase IV(b) synthesis Announcement of Opportunity (AO). A number of investigators gave summaries of their current work, which provided a basis for development of ideas for future analysis, synthesis, and modeling of the Northwest Atlantic/Georges Bank Program data sets. Similar open meetings were held at the previous US GLOBEC AO calls.

PUBLICATIONS:

Groman, R.C., P.H. Wiebe, M.D. Allison, and G. Heimerdinger. 2004. U.S. GLOBEC Data Management. American Geophysical Union, 2004 Ocean Sciences Meeting, Portland, Oregon. January 26-30. (OS32C-24). Eos. Trans. AGU: 84(52) page OS99 [Poster]

Wiebe, P.H., R.P. Harris, O.S. Astthorsson, C.S. Werner, M.A. St. John, D.B. Haidvogel, F. Carlotti, and B. De Young. 2004. Basin-scale Analysis, Synthesis and Integration (BASIN) of oceanographic and climate-related processes and the dynamics of plankton and fish populations in the North Atlantic Ocean (a Workshop). 2004 ICES Annual Science Conference, Vigo, Spain 22-25 September. ICES CM 2004/P:43 page 208. [Poster]

OUTREACH ACTIVITIES:

Web Site:
The principal web site through which data and information from this project can be accessed is: http://globec.whoi.edu. The web site is accessed by over 4000 unique sites a month and reflects the broad interest that our research and these data have for educational, governmental, and

commercial interests. In addition to the large number of US educational accesses (about one third of the total in May 2005 for example), the top non-US accesses were from France, Canada, Romania, Italy, and the United Kingdom.

CICOR Report for the NOAA Grant NA17RJ1223

The Oceanic Role in Tropical Atlantic Climate Variability on Interannual to Decadal Time Scales

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Program Manager: Dr. James Todd, NOAA CLIVAR Atlantic

PROJECT SUMMARY:
The SST dipole is a leading statistical mode of climate variability in the tropical Atlantic Ocean. Most previous studies have focused on the feedback between the SST gradient and the wind speed. The less studied aspect in the climate mode is whether the ocean dynamics play an active role. With this NOAA grant, we have studied how the ocean responds and feeds back to the dipole-induced wind anomaly by analyzing observational data, atmospheric reanalysis outputs, an OGCM simulation result, and by conducting process-oriented numerical modeling experiments. The data analyses indicate that there is a weak positive feedback that the cross-equatorial wind stress is closely coupled to the SST gradient on monthly time scales with no discernable lag, that the period January-June is the most active period of coupling. Northward (southward) anomalies of cross-equatorial wind stress are associated with a substantial negative (positive) wind stress curl. This wind-stress curl drives a cross-equatorial Sverdrup transport in the ocean from the warm to the cold side of the equator with a temporal lag of only a few months — opposite to the winds. The oceanic observations of sub-surface temperature and a numerical model hindcast also indicate a clear relationship between this mode of wind-driven variability and the change in the zonal transport of the North Equatorial Countercurrent (NECC). We estimate that the time-dependent oceanic flow is capable of providing a significant process to the damping of the SST dipole, but that external forcing is essential to sustaining the coupled variability. The result was published in *Journal of Physical Oceanography* (Joyce, et al., 2004).

The variability of the NECC transport is an important component of the oceanic feedbacks to the dipole-induced wind anomaly. Thus we decided to study key processes that contribute to the NECC variations on seasonal and interannual time scales by using satellite altimetry data and an ocean model. The T/P data indicate that the seasonal variability of the NECC geostrophic transport, between 3°N and 10°N, is dominated by SSH changes in the southern flank of the current. Since the southern boundary of the NECC is located partially within the equatorial waveguide, the SSH variation there can be influenced strongly by the equatorial dynamics. We hypothesize therefore that the local wind stress forcing along the equator is the leading driver for the seasonal cycle of the NECC transport. The wind stress curl is an important but smaller contributor. This hypothesis is tested by several sensitivity modeling experiments that are designed to separate the two forcing mechanisms. In the first sensitivity run, a wind stress field that has a zero curl is used to force the ocean model. The result shows that the NECC geostrophic transport retains most of its seasonal variability. The same happens to another experiment in which the seasonal wind stress is applied only within a narrow band along the equator outside the NECC range. To further demonstrate the role of equatorial waves, we ran another experiment in which the wind stress in the southern hemisphere is altered so that the model excludes hemispherically symmetrical waves (Kelvin waves and odd-numbered meridional modes of equatorial Rossby waves), and instead, excites only the anti-symmetrical equatorial Rossby modes. The circulation in the northern tropical ocean, including the NECC, is affected considerably even though the local wind

stress there remains unchanged. All these appear to support our hypothesis. The result for the seasonal variation of NECC has been submitted to *Journal of Physical Oceanography* (Yang and Joyce, *in press*). We have started to examine mechanisms for interannual variability of the NECC transport. Wind stress from both NCEP and the new ECMWF reanalyses has been re-gridded to our model domain. The result from the numerical results will be compared with both altimetry and historical heat content data derived from temperature observations. Our initial test suggests that the forcing from the local wind-stress curl becomes increasingly more important for longer time-scale variability.

Another topic that we have investigated is how the high-latitude climate signals negotiate the crossover between the Deep Western Boundary Current (DWBC) and the Gulf Stream (GS). Changes in high latitude production of the various components of North Atlantic Deep Water (NADW) are of considerable interest as they have been linked to changes in global climate state. The mechanism of teleconnection between changes in the high latitude N. Atlantic and the global atmosphere are not clear, however. It has been shown that the ocean may provide the teleconnection bridge by rapidly exporting atmospheric signals that affect the N. Atlantic Ocean through internal Kelvin and Rossby wave propagation. These can spread information about rapid change in the thermocline depth globally. The propagation of climate signals along the western boundary, however, will encounter an abrupt change of potential vorticity (PV) at the DWBC/GS crossover due to the thermocline depth changes. Observations have indicated that this PV barrier could block, at least partially, the equatorward flow of DWBC. In addition to GS/DWBC crossover, the continental slope also affects the PV and thus the propagation of high-latitude signals. A simple model is used to examine how the presence of a continental slope along the western boundary, and wind-driven gyres, especially the Gulf Stream (GS) jet, affect the pathways of water-mass flow and wave propagation in the abyssal ocean. Two types of forcing: an interior source and a boundary inflow (to mimic the Labrador Sea Water and the Nordic Seas overflow), are considered here. Both topography and wind-driven gyres considerably alter how the water mass spreads from the source (in the steady state case) and how transient signals propagate to the unforced regions. Sloping bathymetry near the western boundary allows for meridional propagation of topographic waves. The GS jet creates a strong meridional PV gradient which could partially block the southward water-mass transport and wave propagation. The effectiveness of the crossover to disrupt the lower layer response depends on the type of high latitude water mass forcing. The result was published in *Geophysical Research Letters* in 2003 (Yang and Joyce, 2003).

PUBLICATIONS:

Yang, J. and T. M. Joyce, 2003: How do high-latitude North Atlantic climate signals negotiate the crossover between the Deep Western Boundary Current and the Gulf Stream? *Geophy. Res. Lett.*, **30**, No. 2, 1070, doi:10.1029/2002GL015366.

Joyce, T. M., C. Frankignoul, J. Yang and H. E. Phillips, 2004: Ocean response and feedback to the SST dipole in the Tropical Atlantic. *J. Phys. Oceanogr.*, **31**, 2525-2540.

Yang, J. and T. M. Joyce, 2004: Local and equatorial forcing of seasonal variations of the North Equatorial Countercurrent in the Atlantic Ocean, *J. Phys. Oceanogr.*, in press.

NOAA Progress 2005 Report

A Fifty-Year Analysis of Global Ocean Surface Heat Flux

NOAA Grant: Task III of NA17 RJ1223 sub-point 51
June 1 2004 – April 26, 2005

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Related NOAA Strategic Plan Goals:

Goal 2. Understand climate variability and change to enhance society's ability to plan and respond.

RESEARCH HIGHLIGHTS

I. Summary of major results

(1) OAFlux Product

The project, Objectively Analyzed air-sea heat Fluxes (OAFlux), has so far developed turbulent latent and sensible heat flux product with daily and 1°×1° resolution for the global ice-free oceans for the period from 1980 to 2003. We are working on extending the product to cover the period from the mid 1950's to the present. The development is based on a weighted objective analysis that combines satellite retrievals, outputs of numerical weather prediction models, and ship reports from COADS. The resulting product has been calibrated and validated with in situ flux measurements. The OAFlux dataset along with net surface short- and long-wave radiations obtained from the International Satellite Cloud Climatology Project (ISCCP) are available via the WHOI ftp site: ftp://ftp.whoi.edu/pub/users/lyu/flux.

(2) Role of air-sea heat fluxes in seasonal evolution of SST in the tropical Atlantic Ocean

The role of surface heat fluxes in seasonal SST evolution is investigated using the new flux product along with SOC flux climatology and NCEP/NCAR and ERA40 reanalysis flux products. The objectives of the study are twofold. One is to gain a better understanding of the mechanisms governing SST variations on seasonal timescales and the other is to identify the differences/similaries between products using a physical relation. If oceanic processes are not considered, the change of SST is related to the net surface heat flux (Q_{net}) by: $dSST = dt \cdot Q_{net}/\rho c_p h$, where h is the mixed layer depth and dSST represents the increment in SST within one month (dt). dSST is calculated as the mean difference between the last five days and the first five days of the month. Fig.1 shows the correlation between dSST and the four sets of Q_{net} products. OAFlux+ISCCP Q_{net} shows that dSST correlates highly with Q_{net} (γ>0.9, significant at 99% confidence level) over most of the tropical Atlantic except two belt regions, one is the ITCZ belt

and the other is the central and eastern equatorial cold tongue. In these two regions ocean dynamic processes are known to play a key role and so it is not a surprise that the correlation between dSST and Q_{net} is low. OAFlux+ISCCP and SOC net heat fluxes yield a similar correlation pattern over most regions except the central Atlantic Ocean between the equator and 8°N. By comparison, correlating dSST with the two NWP model fluxes produces very different patterns in the equatorial region.

The analysis of SST and the mixed layer depth relation based on the Levitus WOA98 upper ocean temperature structures (Fig.2) not only supports the importance of Q_{net} in seasonal variations of SST but also verifies the quality of the OAFlux+ISCCP product.

(3) Detecting decadal changes in air-sea heat fluxes in the Atlantic Ocean during the 1990s
The heat exchange between the atmosphere and the ocean in the Atlantic basin underwent a major change in 1990s as suggested by OAFlux+ISCCP data (Fig.3). The change is characterized by a significant upward trend in turbulent latent and sensible heat loss from the ocean and a slight downward trend in net radiation into the ocean, with the former dominating the net heat flux pattern; and the trend was more pronounced in the southern Atlantic Ocean with the amplitude of the net heat flux into the ocean dropped by more than 20 Wm^{-2} during the decade. Similar trend was also detected in observed upper ocean heat content and moisture content in the atmospheric boundary layer. It appears that the changes in the surface heat fluxes were coordinated with the changes in near-surface atmospheric circulation and upper ocean thermal field.

(4) Verifying flux reference sites for the Indian Ocean observational network design

L.Yu provides surface heat flux analysis for flux reference sites in current planning of the Indian Ocean observational network through serving as a member for the international Indian Ocean Implementation Panel. Six flux products including OAFlux+ISCCP are analyzed (Figs. 4-5), which shows that bias is the major issue. In the eastern Indian Ocean and Bay of Bengal in particular, there is a strong disagreement on whether the ocean receives from or loses heat to the atmosphere on annual basis. The chosen flux reference sites locate not only in regions of strong ocean-atmosphere interactions but also in regions where currently available flux products are widely divergent in terms of their net mean values of air-sea heat exchange. The observational data from these sites will be valuable in understanding and resolving the biases in the various flux products and leading to improved heat flux products.

LISTS OF PUBLICATIONS AND PRESENTATIONS

Publications:

- Yu, L.**,** R. A. Weller, and B. Sun, 2004: Mean and variability of the WHOI daily latent and sensible heat fluxes at in situ flux measurement sites in the Atlantic Ocean. J. Clim. 17, 2096-2118.
- Yu, L., X. Jin, and R. A. Weller, 2004: Variability of air-sea heat fluxes in the Atlantic Ocean indicated from the WHOI analysis, the SOC analysis, and NWP reanalyses. Proceeding of the AMS 13th conference on the interactions of the sea and atmosphere. Portland, Maine. August 2004.
- Yu, L., R. A. Weller, and B. Sun, 2004: Improving latent and sensible heat flux estimates for the Atlantic Ocean (1988-1999) by a synthesis approach. J. Clim.*,* 17, 373-393.
- Sun, B., L. Yu, and R. A. Weller, 2003: Comparisons of surface meteorology and turbulent heat fluxes over the Atlantic: NWP model analyses versus moored buoy observations. J. Clim.*,* 16, 679-695.

Oral presentations given by L.YU:

- Detecting decadal climate variability in the Atlantic Ocean through integration of in situ time series with satellite and reanalysis fields. NOAA Climate Observing Program Annual System Review. April 2005.
- Mean and variability of air-sea heat fluxes in the Indian Ocean. Indian Ocean Climate Symposium. Hobart, Australia. March 2005. Invited.
- Application of scatterometer wind measurements to improve daily turbulent latent and sensible heat flux estimation over the global oceans. NASA/NOAA workshop on the ocean surface vector wind. Miami, FL. February 2005. Invited.
- Air-sea heat flux variability in the eastern tropical Atlantic Ocean. AGU Fall meeting. San Francisco, CA. December 2004. Invited.
- Variability of air-sea heat fluxes in the Atlantic Ocean. AMS 13th conference on the interactions of the sea and atmosphere. Portland, Maine. August 2004.
- The WHOI daily flux product and its comparison with in situ flux measurements and the SOC Climatology. IUGG2003. Sapporo, Japan. July 2003.
- Biases in surface heat flux products diagnosed from in situ flux measurements. Workshop on reducing biases in coupled model simulations of the tropical oceans. GFDL, Princeton. May 2003.

SUMMARY OF INTERACTION WITH ELEMENTS OF NOAA

The project study addresses climate variability and changes on seasonal, interannual, and decadal timescales, which contributes to NOAA research emphasis on detecting, identifying, and understanding the climate change. The project study provides the best possible estimates of air-sea heat fluxes, which contributes to NOAA research need on model validation and initialization.

SUMMARY OF EDUCATION AND OUTREACH ACTIVITY

The project has sponsored two postdoctoral investigators, Dr. Bomin Sun (September 2000 – December 2001) and Dr. Sudharshan Sathiyamoorthy (January 2003 – July 2004). The project has also hosted Ms. Hua Jiang (June 2002 – December 2003), a visiting Ph.D student from Ocean University of Qingdao, China to participate flux validation analysis.

Appendix I: Publication Statistics

	JI Lead Author				Other Lead Author			
	FY01	**FY02**	**FY03**	**FY04**	**FY01**	**FY02**	**FY03**	**FY04**
Peer-Reviewed	26	40	37	13	0	0	0	5
Non-Peer-Reviewed	0	23	15	12	0	0	0	0